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ABSTRACT

Twelve articles dealing with telecommunications systems are presented. The articles are for the most part considerations of some of the potential uses and of the technical problems of communication networks used for commercial and educational purposes. Among the topics are the application of communication technology to control pollution, the CATV (Community Antenna Television) video microwave link, the computer in industry, coaxial cable transmision, and the 12 GHz band. (JY)

GTE LENKURT

DEMODULATOR

1971
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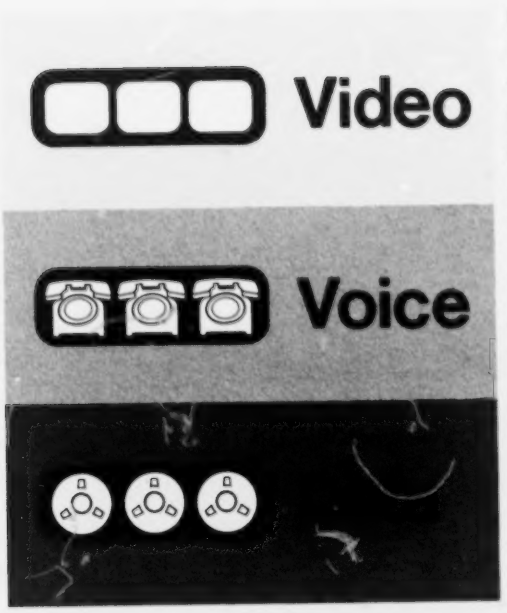

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The Lenkurt

JANUARY 1971

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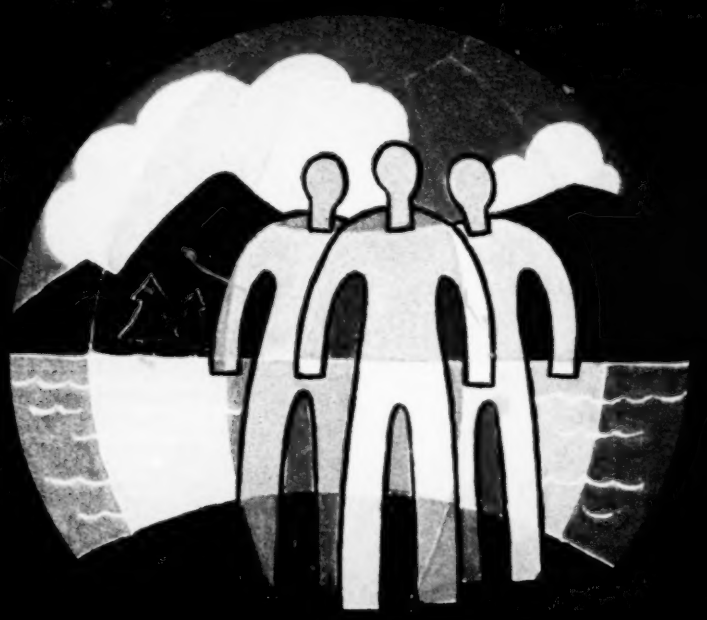

communications and the environment

Proper application of today's communication technology can bring people together and improve the atmosphere in which they live.

Environment includes not only geographic features, but also the people and the subsequent culture of an area. Present communication links can be expanded for environmental channels – voice and video channels for education and exchange of ideas, as well as data channels for earth resources management. This expansion can be realized by utilizing today's communications technology.

Remote data collection and centralized computer analysis of the data can provide an efficient means of measuring, analyzing, and correcting environmental pollution. By providing more channels of communication, more opportunities for expression of ideas through dialogue would be available. These communication channels can be provided by increased two-way video, voice, and data communication.

Pollution Control

Although it is not physically or financially feasible to establish manned laboratories in every geographic location where pollution is most likely to occur, it is possible, by means of a network of unmanned data collection stations, to sample the surroundings and transmit information on air, earth, and water conditions to a central processing laboratory for analysis. In this way, computer technology and remote data acquisition can contribute to pollution control.

Prototype pollution monitoring systems are presently in operation. What look like ordinary navigation buoys are really ocean pollutant detectors. Instrumented buoys, anchored in oceans and inland waterways are equipped with sensor systems and automatic data handling equipment. These unattended buoys are able to measure and transmit such data as water and air temperature, wind speed and direction, and barometric pressure. Such systems are being designed for low-power consumption and long-life expectancy which should provide easily-maintained, low-cost environmental monitoring. A network of ocean monitoring buoys, or stations can communicate with a central processor either over a direct microwave link or via satellite relay links (see Figure 1).

Another pollution detection device now under development employs a patrol aircraft that measures the changes in microwave radiation from the surface of the water (see Figure 2); thereby, determining what the pollutant is – oil or gas – and how thick the spill is.

Similar tests can also be made on the atmosphere to detect air pollution. The proper transmission links permit measurement at many remote locations and processing at one location. Depending upon the results of the analyzed data, the proper corrective

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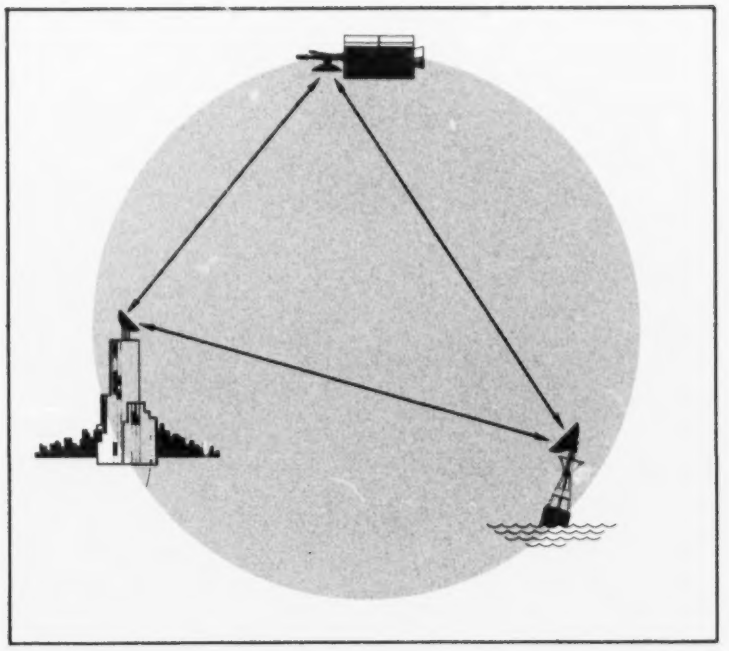


Figure 1. Satellite relay techniques are used to monitor natural resources when a direct microwave link is not practical or feasible.

actions can be transmitted by the central processor for the particular pollution location.

Information can be transmitted from the data collection points to a central processor by microwave techniques. For getting information from the remote data collection points, satellites seem to offer a convenient means. In some cases, depending upon the type of data being collected, the satellite may be able to actually gather the raw data and transmit it directly to the central processor without a surface-collection system.

Satellite Network

A network of satellites and surface-probing sensor systems may be used to study natural resources. In addition to the oceans and air, this network can take inventory of what, where, and how well forests and crops are growing, and the condition of the soil and its ability to be put to work; thus permitting regional, national, or global predictions of crop yields, livestock inventory, and patterns of fire, insect, and disease damage. Information about stream and river flow, excess surface water, pollution, and glacial action can be studied in order to plan better irrigation and flood control systems, develop and maintain water resources, and control erosion.

Air pollution is generally correlated with population distribution and geographic features that can be studied with satellite mapping techniques. Detailed maps of the earth's features can be used for planning land use, urban development, and transportation facilities. Aerial data collection can also be used to map ocean currents, ice, and other navigational hazards. Fish and other marine biology of interest, as well as pollutants, can be studied for the seafood industry, shipping, and marine ecology.

Surface-collection relay satellites and remote-sensing satellites, along with non-satellite remote sensing devices — including sounding rockets, balloons, aircraft, buoys, and ground-based platforms — are capable of transmitting the gathered information

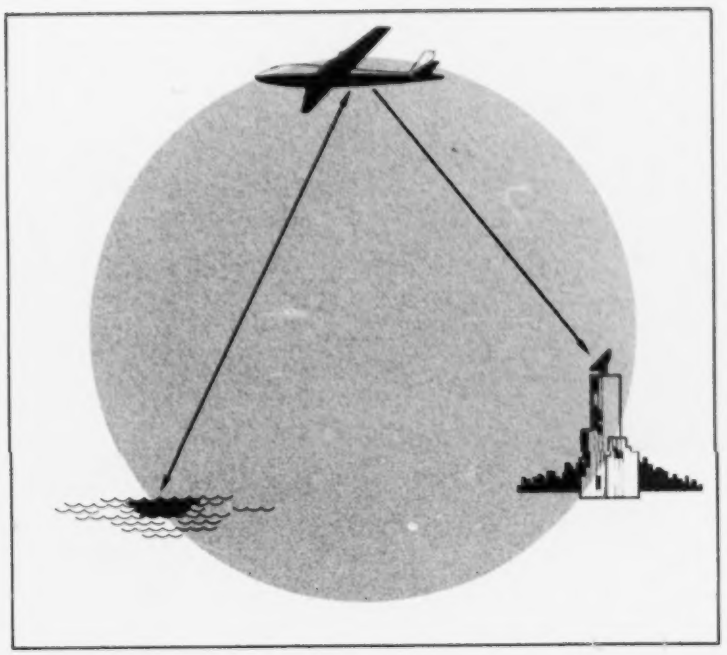


Figure 2. Airborne systems detect petroleum spills in the ocean and transmit the information to a central office for cleanup operations.

to a central computer. The computer's role in this overall environmental management system is that of soothsayer — if, for example, a decision were made to irrigate thousands of square miles of desert to create a new agricultural area, the computer could predict such things as the plan's effect on: climate, population, water resources, and international trade.

In order to manage world resources effectively, adequate information must be available. Information has for centuries been gathered by man on the surface of the earth. In recent times, aerial observations have broadened the field of view, the amount, and the usefulness of the information. With the mass acquisition of data and sophisticated computer processing, it may be possible to stem the tide of diminishing resources, and pollution of the existing resources.

Human Environment

Solving the problems of an area's pollution and diminishing natural resources will do little to improve the total environment, if the people in the area are unable to communicate and clear up differences. These differences often represent a widening gap between expectations, and reality. In an affluent society, we expect more, and better communications are raising these expectations. Through proper education and exchange of ideas it is possible to bring expectations in line with reality.

The areas of communication offered to bring expectations closer to reality include: education, community expression, cultural enrichment, and politics. Some specific services offered include: home library service, facsimile, delivery of mail, crime detection and prevention, remote data acquisition and central processing, educational television, remote participation at conferences, and armchair shopping.

Expanded Services

These new services can be divided into two classes: one-way transmission with no interaction between transmitter and receiver; and two-way trans-

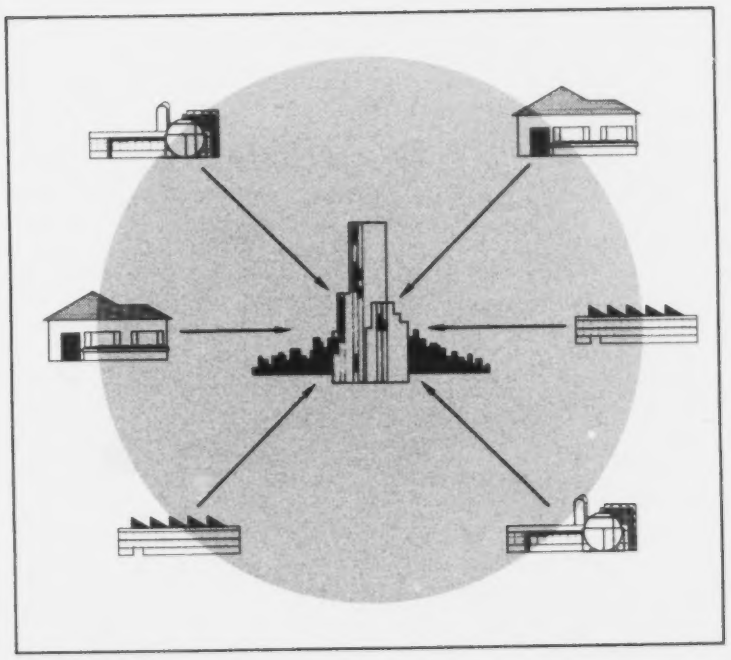


Figure 3. Utility meter-reading employs one-way transmission from many subscribers to one central office.

mission where there is a transmitter and receiver on both ends which provides the opportunity for interaction and response.

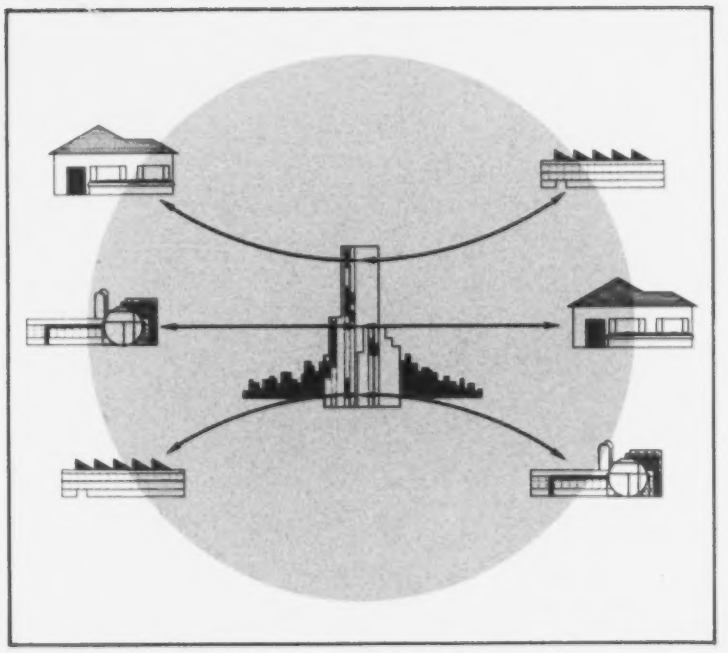
Utility meter-reading is one-way transmission from many subscribers to a central office where the information is processed (see Figure 3). The gathered data from each subscriber is sent through a central processing unit for charge computation. The actual billing could be included in the processing, which would make meter-reading a two-way transmission process. But, it is more likely that billing will continue to use a centralized mail distribution system, since it would not be economical for utilities to operate their own video or data transmission system.

Facsimile (the art of sending pictures or other printed material) is a form of one-way transmission in that there is no interaction between the transmitter and receiver, but both terminals are transmitter/receivers. As technology advances, it may eventually become economical to bring facsimile into the home for such things as home library service and newspaper distribution – if a printed copy of the transmitted image is desired. The transmission of color is possible as demonstrated by color television, but a color facsimile printout device needs to be perfected. Law enforcement agencies are using black and white facsimile printers to speed information across the country for crime detection and prevention. The addition of color would offer improved image recognition.

If printed copy is not needed a video system like television provides readable, although not permanent, written material. The information is read directly off the screen and when finished, the viewer terminates the signal. Cable television, with local programming, could provide channels to bring these services – library and newspaper – into the home. Video-phone service could also bring these visual images into the home.

Mail transmission and distribution, as well as video-phone, is a two-way transmission service that could use

Figure 4. Mail transmission and distribution, as well as video-phone uses a switched network.



the same transmission and distribution plan that is presently used for telephone service. That is, a switched network where an individual sends his message through a central office which redirects the message to the receiver (see Figure 4). With mail transmission and distribution, the service need not be completed at the same time; therefore, delaying the interaction or response. This delay would provide for more efficient use of the transmission channels – transmitting mail in non-peak hours. Mail transmission and distribution will not eliminate the letter carrier, but it can relieve the letter carrier of over 75% of his load without transmitting actual correspondence – personal, business, and government letters – over the air or through a cable. The receiver for such a system could be either a facsimile printer or a video screen depending upon whether printed copy is needed for future use. Another plan gives the sender a choice of transmission modes – instantaneous transmission over telegraph lines to the receiving "post office" where a letter carrier would deliver the message or letter "posting" common today where the original document is "hand" carried to its destination.

Totally automated system monitoring is a two-way system using programmed transmitter/receiver terminals. This is essentially the same technique used for natural resource control, but also used for monitoring other remote systems. Remote data access and central processing also includes time-sharing computer service. As the complexity and cost of these terminals is reduced, more people will take advantage of the benefits offered.

Educational television and remote conference participation are similar to video-phone with instantaneous voice and video communication. Where these services differ from video-phone is that there is a central transmitter/receiver and many remote transmitter/receivers that interact with the central unit (see Figure 5). Using such a service, government officials have direct contact with their constituents. This service has the greatest potential

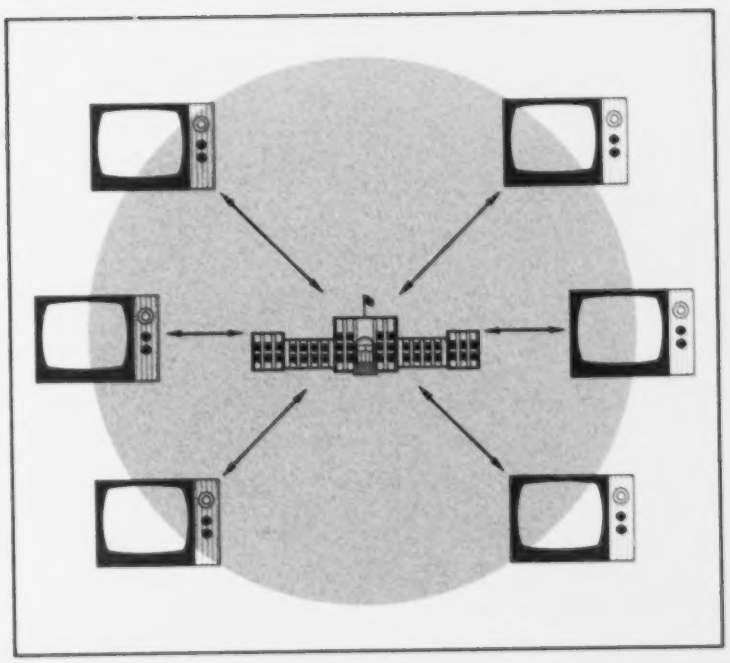


Figure 5. There is two-way communication between one central location and many remote subscribers for educational television and remote conference participation.

for bringing people together because it is possible to clear up any misunderstandings that might arise before they have a chance to cause dissention in the ranks. This service could put expectations and reality into proper perspective. Communities can express themselves over a two-way voice/video channel so the public has the opportunity to know the full story and to express their approval or objection. And, educational television provides the means for educating large masses in one geographic region or select groups scattered over several regions. Increased educational facilities provide the means to close the gap between expectations and reality.

New Direction

Expanded means of communication have the potential to provide a more efficient society with an informed public living in a healthy, plentiful environment. Presently, the possibilities are practically unlimited, but so are the possibilities for this expansion getting out of control. If the best interests of the public are to be realized, the most efficient and most economical systems must be put into effect. None of these expanded services will be totally adopted unless present costs can be substantially reduced. Technology has developed these services, economics will dictate their future.

The *Lenkurt*

FEBRUARY 1971

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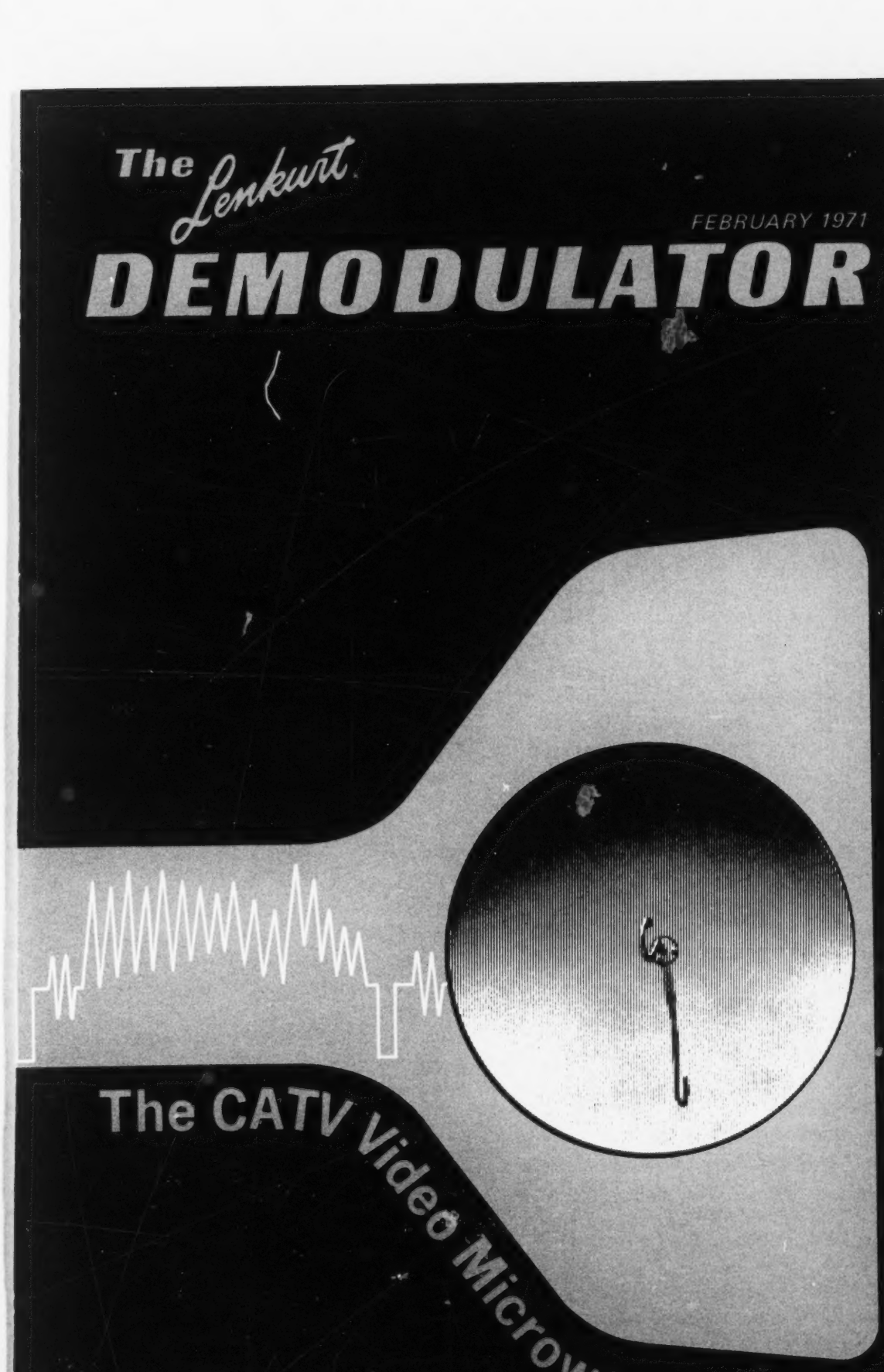

The CATV Video Microwave Link

From its beginning as a tiny measure of light picked up by a TV camera and changed into electrical energy, to the time it is viewed on the screen, the television signal undergoes a complex adventure on its journey from broadcast transmitter to television receiver.

The television signal leaves the broadcast transmitter as composite video information modulated on an RF (radio frequency) carrier. This composite signal contains the video (picture signals), sound, color, blanking, and synchronizing information necessary to materialize a picture on the television screen (Figure 1). If the path between the transmitter and receiver is straight and unobstructed, viewers will enjoy a good picture with few complications ever arising. However, if TV viewers live in an area where irregular terrain or sheer distance blocks reception of television signals, some means of making television reception available in that area is necessary. Since the distance a television signal travels after it leaves the broadcast transmitter is generally limited to a line-of-sight characteristic, reception is confined to a relatively small geographical area. One method of extending TV programs to viewers in remote areas is by use of a microwave CATV (Community Antenna Television) system (Figure 2). In this type of system, an off-the-air pickup of the television signal is made at a "head end" station. Here the signal is amplified and processed to produce a TV baseband signal which is essentially a duplicate of the original TV baseband signal that went into the input of the distant broadcast transmitter. This signal is then relayed by a series of line-of-site repeaters to the remote area.

The types of microwave repeaters, their methods of operation, their appropriateness in certain systems, and their overall performance in a multihop video microwave link constitute some aspects of a CATV system that are discussed in this article.

A system of line-of-sight repeaters which amplify the incoming microwave signal and send it on its directed path comprises the major part of a video microwave system. One of the most important considerations in the planning of a microwave installation is choice of equipment which will accommodate future growth expectations and at the same time provide satisfactory video information at the initial terminal point.

The microwave repeater performs two important functions. The first of these functions is to amplify the incoming signal sufficiently so that it may reach the next repeater. The amplified output signal may be anywhere from 55 to 105 dB greater in power than the incoming signal. Secondly, the repeater must convert the incoming signal to a different frequency so that in transmission the outgoing signal does not interfere with the

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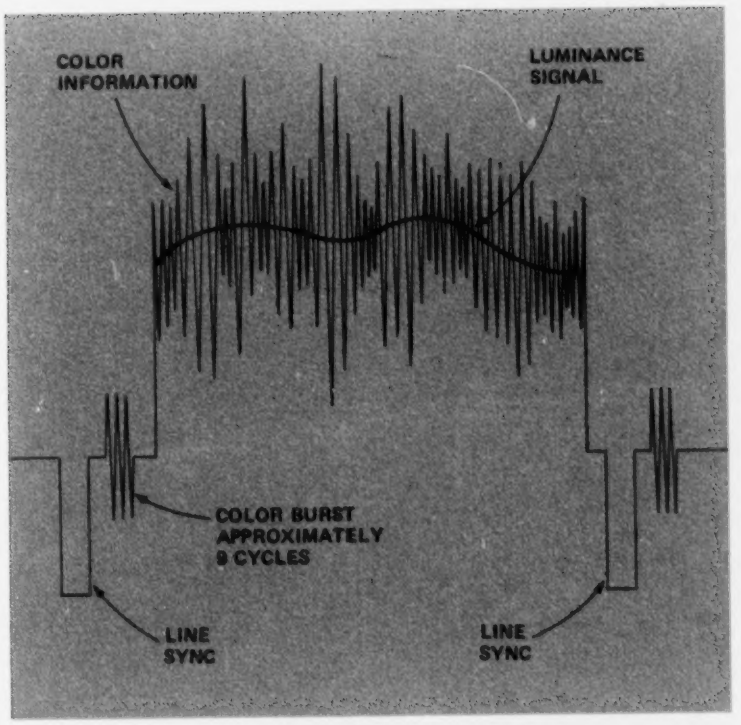

Figure 1. The composite video signal. The color burst is transmitted during the blanking pulse serve as a phase reference for the color information which modulates the basic video or luminance signal.

incoming signal; interference usually being due to limitations on antenna front-to-back ratios and foreground reflections. Most CATV microwave systems operate in the CARS (Community Antenna Relay Service) band. In the CARS band the frequency shift is usually 25 MHz or some mutliple of it.

There are three types of microwave repeaters – baseband, IF heterodyne, and RF heterodyne (Figure 3). Video microwave systems use the first two types almost exclusively. Each has advantages and disadvantages which must be considered when planning a video microwave system. Generally the choice of repeaters is based on the distance the microwave signal must travel.

Baseband Repeaters

Baseband or remodulating type of radio equipment is usually employed when designing systems of two hundred miles or less. The baseband consists of the composite video signal, program channels, and supervisory signals that are used to modulate a particular carrier. In a baseband repeater the incoming microwave signal is mixed to produce an intermediate frequency; this is then amplified, demodulated, and amplified again at the original baseband frequency. Lastly, the signal is remodulated and transmitted at the microwave frequency. The baseband repeater is generally used only in short haul applications because each time the video signal is modulated or demodulated, a certain amount of distortion is generated due to nonlinearities in the conversion from amplitude variations to frequency variations.

Since the incoming signal is demodulated to its baseband frequency at each repeater, it is possible to make

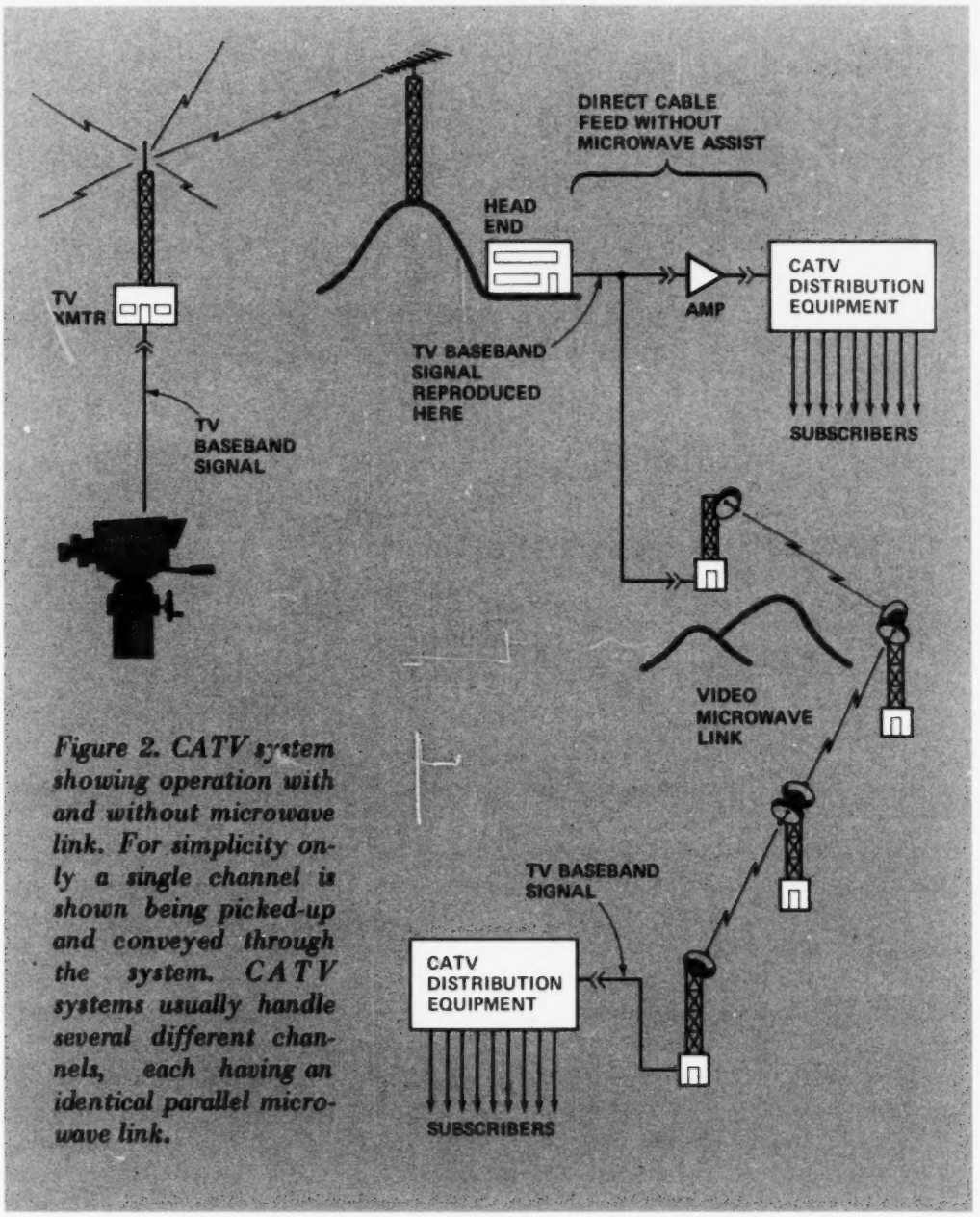

Figure 2. CATV system showing operation with and without microwave link. For simplicity only a single channel is shown being picked-up and conveyed through the system. CATV systems usually handle several different channels, each having an identical parallel microwave link.

television signals available for reception anywhere along the main backbone route. This convenient availability of baseband signals at each repeater is one of the advantages of a baseband system.

Although ten hops in tandem are usually the maximum length considered for baseband type equipment, GTE Lenkurt 76C microwave equipment was successfully used in a 17 hop system, providing low enough distortion in both differential phase (phase variation) and differential gain (gain variation), to permit a color projection on a 30 foot (9.2 meters) by 40 foot

(12.2 meters) screen at EXPO '67 in Montreal.

IF Heterodyne Repeaters

In the IF heterodyne repeater, amplification is performed at the intermediate-frequency stage without going through the demodulation and remodulation process required in the baseband repeater. The incoming signal is first heterodyned to the IF stage. This process involves mixing the incoming signal with a constant signal provided by a local oscillator. The result is two frequencies equal to the sum and difference of the first two, each containing identical information. At this point the difference frequency is amplified, then passed through an up-converter to be translated to the outgoing microwave frequency. The elimination of the demodulation and remodulation process gives improved noise performance since distortion is kept to a minimum. Other advantages of heterodyne repeaters over baseband repeaters are less maintenance, better baseband level stability, higher power output, and greater distance between hops. The greatest limitation of a heterodyne repeater is its cost. Because of its more sophisticated components which include a traveling-wave tube and associated power supply requirements, the cost of the heterodyne repeater is higher than that of the baseband repeater.

In the heterodyne system, the baseband is not as readily available at each repeater station as it is in the baseband repeater although it may be easily acquired by adding a 70-MHz discriminator. In the discriminator, the baseband is separated from the incoming frequency-modulated carrier wave by changing modulations in terms of frequency variations into amplitude variations. The low distortion of IF heterodyne repeaters makes it possible to carry video information over great distances without any appreciable degradation of the picture at the terminal point.

Composite systems utilizing a mixture of both IF heterodyne and baseband repeaters are often used. In a composite system, the heterodyne repeater may form the backbone route of the system while baseband repeaters are used on short side legs to provide local television reception along the route. In some systems, IF heterodyne repeaters are combined with baseband terminals as an economic compromise. The main purpose of these systems is to combine the low costs of the baseband repeater with the low distortion of the heterodyne repeater.

RF Heterodyne Repeaters

Although RF heterodyne repeaters are not presently used in video microwave links, they are mentioned here as a point of interest and to acknowledge their existence. All solid state RF repeaters (though not rated as video capable) are "state of the art" at 2 GHz, and not readily available above this frequency.

The RF heterodyne repeater provides amplification directly at the incoming microwave frequencies. The incoming microwave signal is first amplified, then heterodyned with a signal at the shift frequency to produce an output at the desired microwave output frequency. This latter is then filtered and amplified for transmission over the next hop. The prohibitive cost of the RF heterodyne repeater makes it a seldom used item. This high expense manifests itself in the form of providing gain at microwave frequencies, producing filters selective at microwave frequencies, and provision of adequate limiting, automatic gain con-

trol and delay distortion correction – all necessary, all expensive.

Overall Performance

Published industry standards are available as guide lines for calculating overall color video performance*. EIA has established a standard of 0.6 dB as maximum differential gain and ±1.5 degrees as maximum differential phase that should exist in an overall system. These standards are established relative to the maximum gain at 50% APL (average picture level). Actual performance measurements taken at an operating microwave installation may show performance to be within these tolerances. For example, in a 6-hop IF heterodyne system, the total differential gain may be 0.3 dB and the total differential phase may measure 0.4 degrees. A 6-hop baseband system has shown measurements of 0.5 dB for differential gain and 1.0 degrees for differential phase.

Other factors to consider in calculating overall video performance are frequency response and signal-to-noise ratios. Frequency response roll-off on the baseband system has a tendency to accumulate at a predictable rate; roll-off being the gradual increase in attenutation as frequency is varied in either direction beyond the flat protion of the frequency response curve. This attenuation rate can be reduced by utilizing correctional amplitude equalizers as required, thus tailoring individual hop frequency response.

In an IF heterodyne system, amplitude response and group delay accumulations tend to have an unfavorable bearing on the video performance. However, by using 70-MHz parabolic and slope equalizers on a periodic basis, a system will show considerably improved video characteristics.

*EIA (Electronic Industries Association) standard RS-250-A.

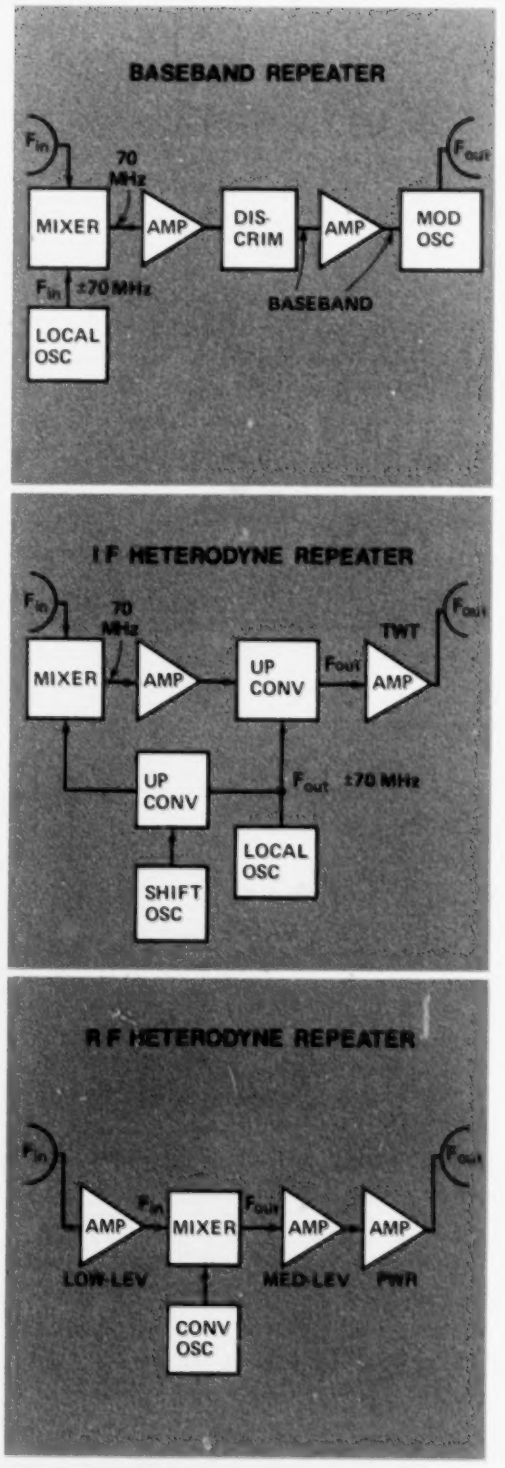

Figure 3. Microwave repeaters are classified by whether they provide amplification at baseband frequency, intermediate frequency, or radio frequency.

Signal-to-noise measurements should be made using weighting networks. In a weighting network an artificial factor is inserted into the measurement to compensate for conditions which, during normal use of a device, would otherwise differ from the conditions during measurement. These conditions are subjective in nature and can be assigned a degradation factor based on their relative effect. For example, background noise measurements may be weighted by applying factors or inserting networks that reduce measured values in inverse ratio to the interfering effect. The essential function of a weighting network is to make the measurement parameters reflect as accurately as possible the degree of annoyance to an average viewer or user. For example, an interfering tone or noise in the higher parts of the video baseband will usually cause less degradation to a viewer than a tone or noise of the same power in the lower portions of the baseband. The weighting network is designed to compensate for these subjective effects, which have been determined by actual trial and error tests on many subjects. Bell laboratories evolved a color TV weighting curve that would apply to various transmission media and which has since been adopted by EIA. Signal-to-noise ratios (peak-to-peak video to RMS noise) of 75 dB per microwave path are normal, and would allow 100 hops before a 55-dB signal-to-noise ratio was attained. An outage level of 33-dB signal-to-noise ratio was adopted by the EIA committee.

In addition to the electronics design problems in a microwave system, there are wave propagation considerations such as path attenuation between two points under free-space conditions, atmospheric and ground effects on propagation, and reflection and refraction effects on the microwave path. Losses due to these effects may sometimes be forecast with some degree of accuracy but loss data due to atmospheric effects for a particular area may be realized only by survey measurements in that area.

Still more considerations in planning a television microwave system include antenna design to be used, location of towers, routine maintenance, adequate temperature controlled housing for equipment, continuous power supply requirements, back-up equipment with automatic switching devices, and security of equipment. Only when these requirements have been completed is there a source of television signals available at the terminal station.

It is at the terminal station that signals are brought to proper levels and remodulated to VHF and UHF frequencies. At this point the microwave link is complete. Signals are conveyed to viewers by means of private distribution systems, usually by means of a cable television system.

Planning, engineering, and even some solid intuition are all necessary for the successful realization of a microwave system that brings daily television programs to home, school, and business.

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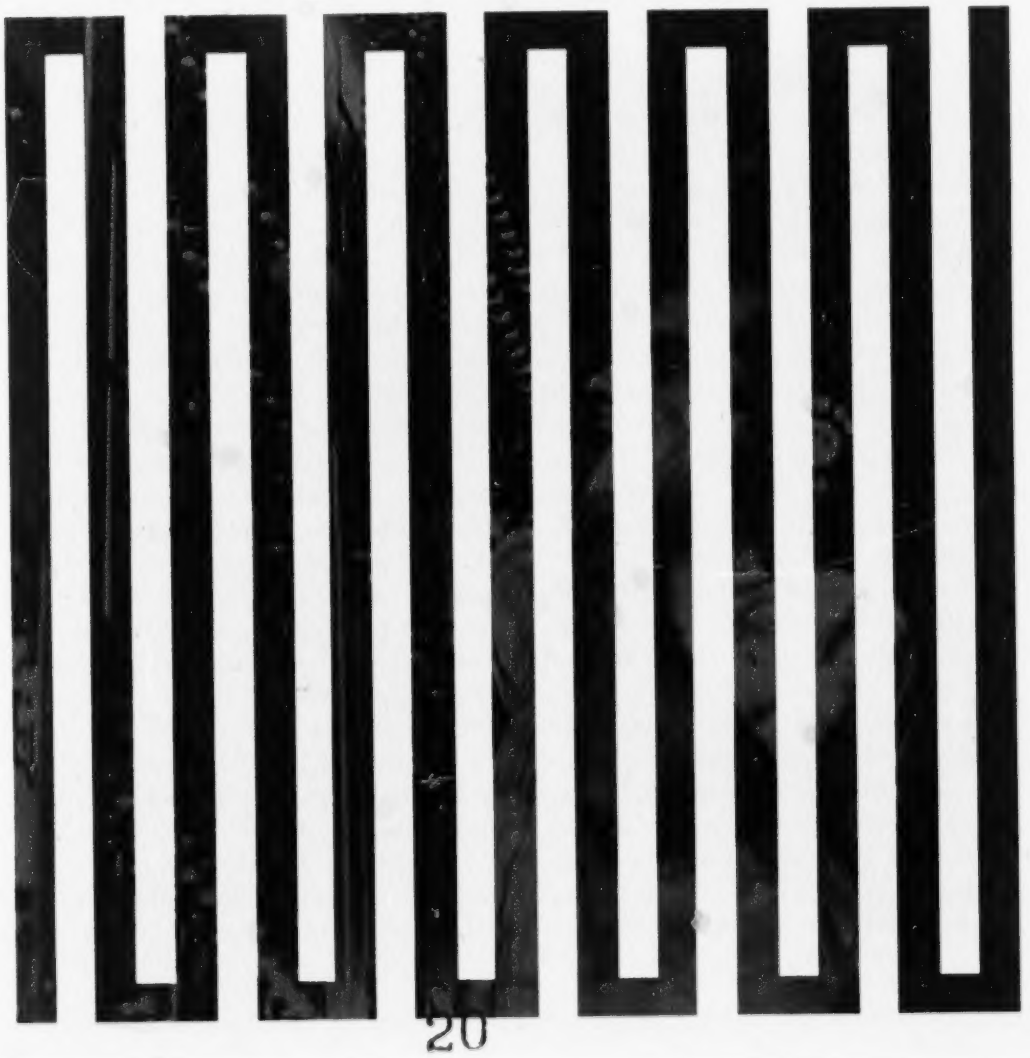
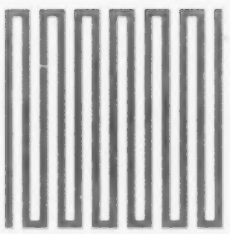
MARCH 1971

PCM Signaling and Timing





The integration of pulse code modulation (PCM) carrier systems into the telephone plant has left personnel, expert in dealing with the traditional frequency-division multiplex systems, grappling with less familiar terms such as "sampling," "quantizing," and "coding."

The principles of message transmission in a PCM system have been described in a variety of articles and books. (See, for example, *The Lenkurt Demodulator*, November, 1966.) While message transmission is, of course, the objective of such systems, it is not the whole story. A message with no place to go is no message at all.

How, then, do PCM systems carry the various types of signaling and supervisory information that control an ordinary telephone call? And how can a PCM carrier system integrate into an existing plant that already includes such diverse types of signaling as E&M (receive and transmit), loop dial, and foreign exchange? Furthermore, how are these signaling and supervisory functions handled in second generation PCM systems?

The answers to these questions are inextricably bound up with the carrier's nervous system – the timing arrangement that sorts out more than a million-and-a-half information bits each second to form individual message channels and their associated signaling information. A good starting place is a brief review of the transmission techniques used in first-generation PCM systems. These systems are built by several manufacturers. Regardless of their origin, however, they conform to the same general system parameters.

T-Carrier Transmission

For convenience, the entire carrier system is referred to here as a *T-carrier* system, in accordance with the Western Electric Company designation. However, common usage has separated the *T1 repeatered line* from the *D1 channel bank* – the actual multiplex terminal. It is in the D1 bank that sampling, quantizing, and encoding occur. It is also the D1 bank that controls system timing, the all-important brain of the system.

The analog voice signals are first sampled in sequence to form pulse amplitude modulated signals. Each pulse is then quantized – assigned the nearest discrete value to its actual amplitude. Logic circuitry then encodes the pulse into a binary number that defines this discrete value. This binary number is expressed as a series of identical pulses, or spaces. A pulse indicates a binary "1" and a space indicates a binary "0".

The series of pulses and spaces that defines one quantized sample from one channel makes up a PCM word.

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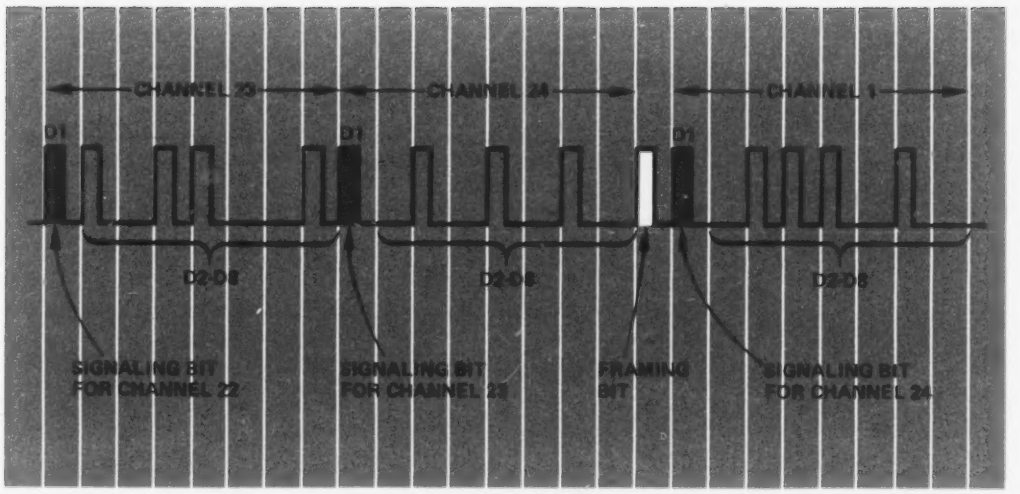

Figure 1. Frame format of D1 channel bank consists of 24 8-bit PCM words plus one framing time slot. The D1 time slot in each word is reserved for signaling information for the previous channel.

The length of the word limits the number of quantizing steps that can be used, and hence the fidelity with which the original analog signal can be reproduced at the receiving terminal. The D1 bank uses a seven-bit encoding scheme, which permits 2^7, or 128, quantizing steps. (Other considerations preclude the use of 0000000, so 127 steps are actually available for quantizing the voice signal.)

However, there is one necessary ingredient in the PCM word associated with one sample from a single channel. This is some way to carry the signaling and supervisory information. In the D1 bank, this is done by adding one additional bit to form an eight-bit word. The first, or D1, time slot in each word is reserved for signaling and supervisory information for the previous channel.

Since the system handles 24 voice channels, 24 eight-bit words (a total of 192 bits) are contained in one scanning cycle – one word from each channel. These 192 bits make up a "frame." Without a means for the receiving terminal to identify the beginning and end of these frames, the transmitting and receiving terminals will not be synchronized and the receiving terminal will be unable to route the individual words to the appropriate channels. Therefore, a 193rd time slot is inserted in each frame, as shown in Figure 1, to provide timing information.

This framing bit alternates between a "1" and a "0" for succeeding frames. The result is a stable signal component at one-half the frame rate. Since the frames recur at a rate of 8-kHz, the alternating framing pulses produce a 4-kHz component, as shown in Figure 2. The framing circuitry in the receiver locks onto the frame rate. In the event of loss of synchronization, the receiver "slips" one bit per frame until it regains synchronization. If it has not regained the frame rate after checking each bit in two frames, an alarm is initiated. It takes 48.25 milliseconds to check these 386 bits.

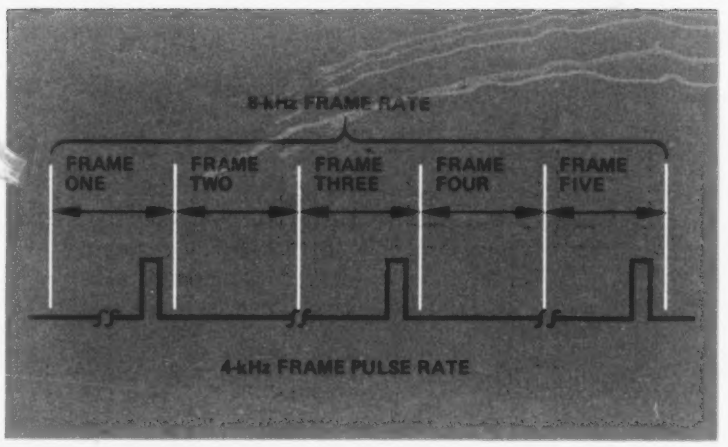

Figure 2. Alternating one and zero framing bits produce a 4-kHz pulse rate to establish the synchronization between transmit and receive terminals.

Transmitting Signaling Information

As far as the D1 bank is concerned, there are two types of nonmessage information to be transmitted: supervisory information (on-hook, off-hook) and signaling information (dial pulses and multi-frequency tones). Supervisory information is transmitted using two possible electrical states such as – open or closed loop; potential on either side of the incoming line; or battery or absence of battery on the signaling leads. These two varying electrical states result in a series of either 1's or 0's in the D1 time slot of, say, channel one. When the electrical state changes, the 1's change to 0's, and vice versa. At the receiving terminal, the series of pulses and spaces is used to reconstruct the original DC potential for transmission to the office switching equipment.

Transmission of dial pulses is nearly as simple as transmitting the supervisory information. Assuming, for ease of calculation, a 50/50 make/break percentage, a dial pulse at a nominal 10-pulse-per-second rate has a duration of 50,000 microseconds. Since a sample is taken every 125 microseconds (in the original D1 bank), each pulse is sampled 400 times. (See Figure 3.) Thus, neither the pulse rate nor the make/break ratio is critical. The PCM system sees dial pulses as slowly changing potentials.

Since there are only two possible states in both supervisory information and dial pulses, neither needs to go through the quantizing process used for voice signals. All that is required is sampling at the appropriate time and conversion to the correct voltage level at the receive terminal. Thus, the signaling and supervisory information enters the transmission path just before the bit stream goes on the line. Conversely, this information is extracted from the bit stream as soon as it comes off the line at the receive terminal.

Multi-frequency signaling tones consist of varying AC within the voice band. Therefore, the D1 bank treats them like voice signals. It samples, quantizes, and encodes them. At the receive terminal, they are reconstructed in the same manner as a voice signal. Thus, when multi-frequency signaling is used, the actual signaling path in the carrier system handles only supervisory information.

There are two possible separate signaling paths through the entire common carrier equipment. Not all signal-

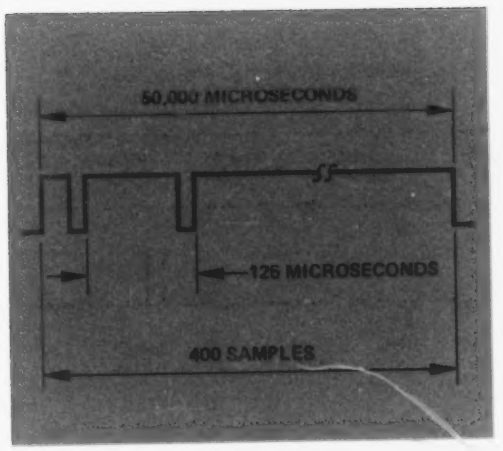

Figure 3. Each dial pulse is sampled approximately 400 times at an 8-kHz sampling rate.

ing arrangements require both paths. Dial pulse and E&M signaling, for instance, each need only one path. However, more complex signaling schemes that must send two types of information simultaneously require both paths.

For example, foreign exchange signaling arranged for forward disconnect must hold the subscriber terminal busy while the office disconnects. It is a matter of controlling two relays, one to hold the subscriber off-hook, and the other to provide on-hook/off-hook information about the office condition. Nevertheless, two separate signaling paths are required for such an arrangement.

Two Paths on One Bit?

Since two signaling paths are necessary for certain types of signaling, and only one bit in each word is set aside for signaling information, how can the two paths be kept separate? Western Electric Company has developed two separate signaling schemes for the D1 channel bank. These two schemes are called *D1A* and *D1B*.

Although only one digit is set aside for signaling, it is possible to borrow one of the voice digits to provide the second signaling path. The D1A arrangement borrows the eighth bit of the PCM word (the least significant bit) to provide the second signaling path. Hence, this option is often referred to as D1/D8 signaling. Even though this technique uses one of the voice digits, it does not affect the quality of voice transmission through the channel; since once the call is established, D8 is returned for exclusive use in voice encoding. A pulse in D1 indicates the channel is in an on-hook condition. When no pulse appears in the D1 time slot, the called terminal has gone off-hook, and message traffic is imminent. The absence of a D1 pulse inhibits the use of the D8 time slot for signaling, freeing the D8 time slot for full seven-bit voice signal encoding.

This arrangement works out well except in cases where the called terminal sends back no on-hook/off-hook supervisory information. These are the so-called "free" calls (to directory assistance or a test line, for example) where there is no reverse battery supervision. In such a case, a pulse appears in the D1 time slot even when the called terminal goes off-hook. Therefore, D8 would continue to be used for signaling, using a digit that would normally be reserved for voice transmission. As a result, the voice signal is encoded in only six bits instead of the usual seven. The increased quantizing noise with 63 quantizing steps, rather than the usual 127, substantially degrades the quality of the voice channel.

This condition is not a universal problem because it only occurs with certain types of signaling – and then only on free calls. Nevertheless, it can

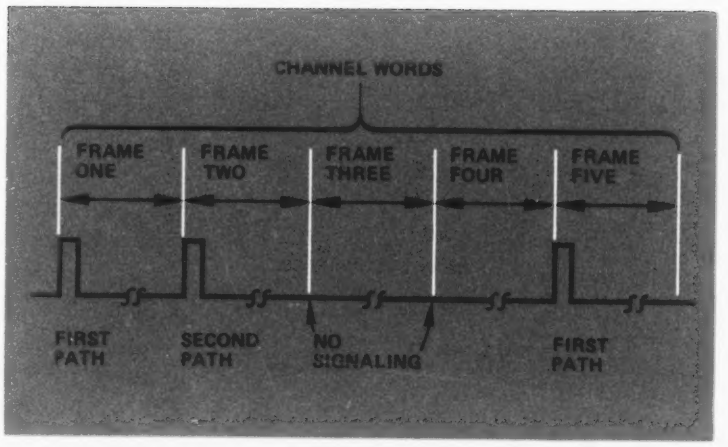

Figure 4. In D1B signaling, the first signaling path is provided by the D1 time slot on first frame, the second signaling path uses the D1 time slot of the second frame, and neither uses it on third and fourth frames.

be avoided with a different technique for providing two signaling paths. This improved two-path arrangement is referred to as D1B.

Since D1B uses only the D1 time slot for signaling, it is sometimes called "D1 only." The D1 time slot in the first frame provides the first signaling path, the D1 time slot in the second frame provides the second path, and both paths are inhibited during the third and fourth frames. Then the pattern repeats. This four-frame pattern, shown in Figure 4, is necessary to avoid confusing the receiving terminal with false framing information. Suppose, for instance, that the signaling paths were to use the D1 time slot in alternate frames, and one of them produced a series of pulses while the other produced no pulses. The resulting series of alternating 1's and 0's would produce a 4-kHz fundamental component that would be indistinguishable from the framing bits.

Each signaling path for a particular channel is sampled only once every four frames and the entire frame length is 125 microseconds; therefore, samples of signaling information are taken every 500 microseconds – or about 100 samples during a typical dial pulse.

Second-Generation PCM Systems

The second-generation PCM carrier terminal is the *D2 channel bank*. Like the D1 bank, D2 uses an eight-bit PCM word. However, the D2 bank is intended to meet intertoll requirements for lengths up to 500 miles. Seven-bit encoding is not good enough to achieve this objective. The quantizing noise would be too high. Therefore, it is not possible to reserve one digit out of the eight to provide signaling information.

The solution is a second level of time-division multiplexing. In five out of every six frames, the D2 bank encodes the voice signal in eight bits. In the sixth frame, it uses only seven-bit encoding, borrowing the eighth bit for signaling information. The result is an average 7-5/6 bit encoding for the voice signal. This improved performance meets the intertoll objectives.

Two signaling paths, for four-state signaling, are provided in much the same way as in the D1B channel bank. The signaling bit in every other sixth frame carries one two-state channel, while the same bit in alternate sixth frames carries the other two-state channel. In this way, complete information about the condition of both signaling paths can be transmitted in

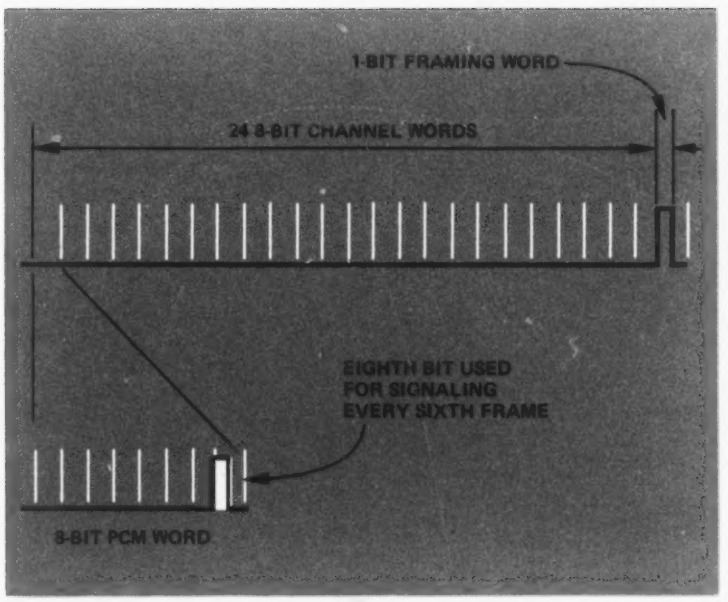

Figure 5. D2 frame format consists of 24 8-bit words plus a 1-bit framing word. Signaling borrows one bit from each channel word, in every sixth frame.

12 frames – about 1.5 milliseconds. If only one signaling path is required, as in the case of E&M signaling, both paths are still used – providing signaling every six frames.

One effect of this time sharing every sixth frame is the necessity for more framing information in the eighth bit of each word. Not only must the receiving terminal recognize the beginning and end of each frame, but it must also determine whether or not a particular frame carries message or signaling information on the eighth bit of each word. Once again the answer is time sharing. The framing bit in every other frame contains the information for terminal synchronization (see Figure 5). This leaves the framing bit in alternate frames free to carry the information necessary to distinguish the one frame in six that carries signaling information.

The net result is a gross frame format and an operating bit rate identical to that of the D1 bank. However, the D1 and D2 banks cannot be operated end-to-end. Not only do their framing and signaling arrangements differ, but they also have different PCM coding schemes and companding characteristics.

While these two channel banks – D1 and D2 – lack such direct compatibility, they can operate over the same repeatered lines. And they are closely related members of the emerging family of digital transmission systems.

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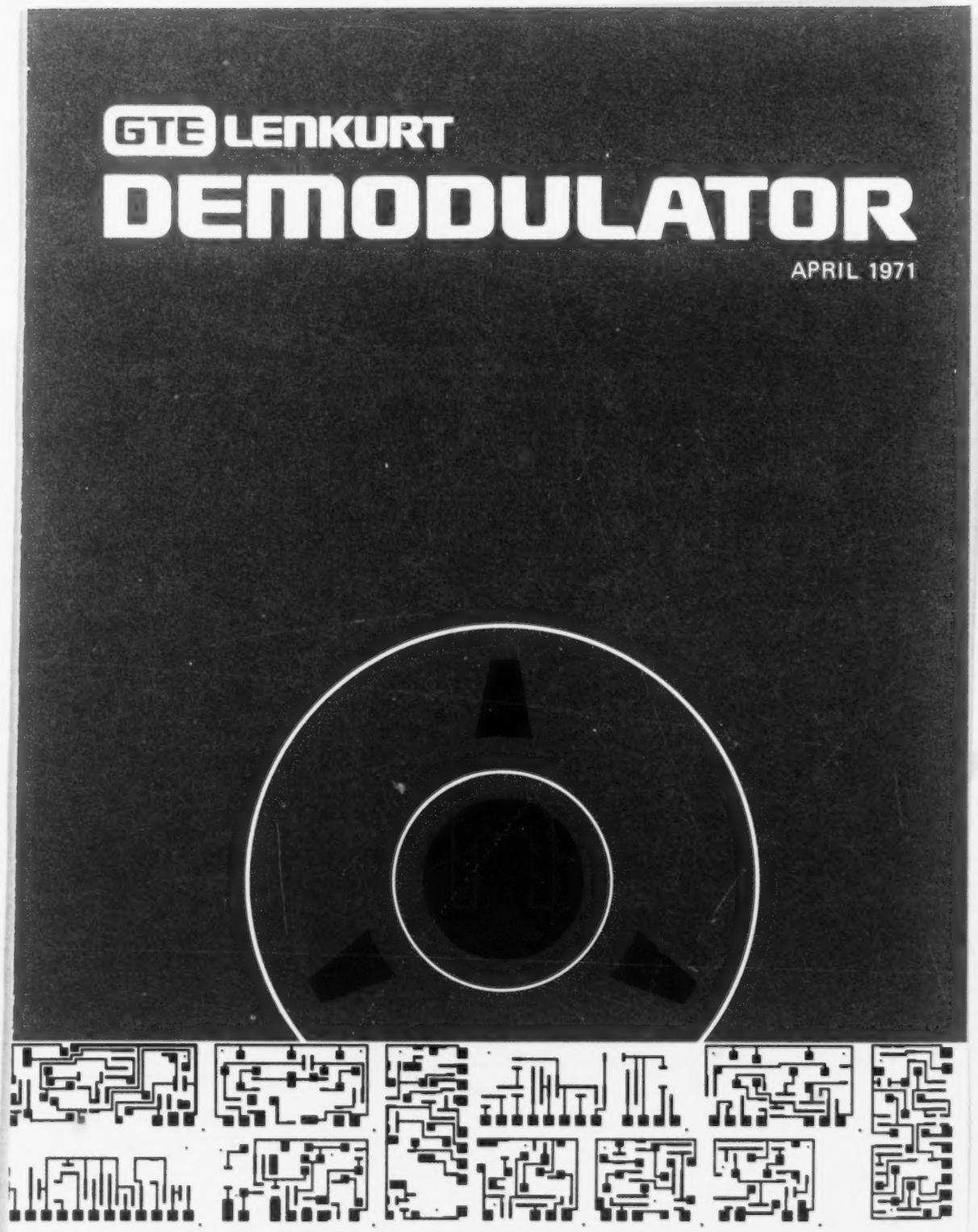

the computer in industry

Computers play an integral part in the design, manufacture, and installation of communications systems, and in dispensing with the associated paperwork needed to carry out these processes.

The new generation of digital computers – the third generation – stresses user conveniences. The associated input-output devices are designed to make man-machine communication as convenient as possible. This third generation has introduced the idea of computer graphics which can convert pages of data into meaningful and useful design concepts. The cathode ray tube and the x-y plotter are the two primary input-output devices that have made these computer graphics possible.

The computer graphics of the third generation complement the capability of the previous generations rather than making them obsolete. This developing and expanding use of the computer is helping industry keep up with rapid changes in all areas of technology.

Engineering Design

Starting with the initial design of a communications system, the computer is a significant aid. One common computer use is in network design and analysis of both passive and active filters. The computer can perform many functions in carrying out the filter design. Synthesis, optimization, performance analysis, and sensitivity analysis are some of these functions.

Knowing the desired input and output characteristics of the filter, the engineer uses a synthesis program to design the filter circuit. With the designer supplying sample frequencies in the stopbands and passbands, the computer calculates the loss at each of these frequencies from which an accurate loss curve can be plotted. According to mathematical equations specified by the computer program, the computer can design a filter circuit to match this loss curve.

If the designer is satisfied with the circuit and predicted performance, an optimization program determines the component values necessary to optimize the circuit parameters.

Once the proper circuit and respective components have been selected, filter performance is checked using the computer. In the performance analysis step, the computer "predicts" such parameters as total loss, phase shift, envelope delay, reflection coefficient, and input impedance.

In order to complete the network design, the computer uses a sensitivity program to study network performance when the components go out of tolerance, the temperature changes, an inductance changes, or any other predictable change occurs. The results of this program give the engineer some idea of how valid his chosen tolerances are and allows him to adjust his tolerances to meet performance requirements while minimizing cost.

When the total system is designed and ready for pre-production and manufacturing, the computer comes into serivce again. Sheet metal template layout, printed wiring card artwork and thick film circuits are some of the areas covered by computer aided design (CAD).

Sheet Metal Templates

Sheet metal template layout by computer is another time saving operation both from the standpoint of prototype layout and production runs – even with design changes. The use of

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the computer to make a master template eliminates the need to hand scribe a sheet of metal that has been covered with a thin coat of paint. In the hand scribe method, the layout man scribes the sheet according to the dimensions given on the engineering drawing for the various items to be reproduced on an actual manufactured sheet metal part. This operation is time consuming and requires a skilled layout man to produce the needed accuracy.

Using this hand scribe method, it becomes even more costly if it is necessary to make an identical template if the first has become worn or because the part is being made in more than one location. And, if design changes are required, an updated engineering drawing is needed before a new template can be scribed.

The major advantage of computer assisted template layout is the ease with which identical templates can be scribed. If instead of scribing lines the layout man puts his time and effort into coding the layout for use with a suitably programmed computer, the second template can be scribed in an average time of 15 minutes, on a flatbed, x-y plotter.

If any changes or modifications are required in the original design, the appropriate changes or modifications are made in the input data before the new template is produced. This input deck is made up of the information from the engineering drawing of the sheet metal part. The mnemonic coding language for template layout uses single letters to designate standard fabrication operations, such as arc, band, countersink, and notch. An added advantage is that the engineering drawing to be coded can show the formed sheet metal part, and the computer can be programmed to compensate for the necessary bend allowances in laying out the flat, unformed template.

Using the computer assisted layout procedure, the designer can check the input data before making the template. This is done by plotting the layout on paper before scribing it on metal. Once this paper plot has been checked, the painted metal for the template is put on the plotter to be appropriately scribed, as shown in Figure 1. Necessary written instructions are scribed right on the template so they are legible and cannot be misplaced.

The coded information used to generate the sheet metal template can also be programmed to generate a punched tape for use on a numerically controlled milling machine for machining holes, slots, counterbores, and other machined operations.

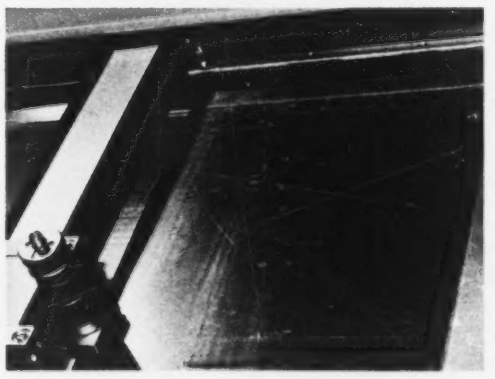

Figure 1. An x-y plotter scribes directly on a painted metal plate to make a sheet metal template.

Printed Wiring Cards

Another area of computer aided design helpful in getting a product into production is printed wiring card (PWC) layout. Under non-computer aided conditions, four different steps are involved after the circuit designer has completed his design. First, a mask must be drawn or taped for the circuit, designating all the wires and component pads. Second, a reverse side mask must be made indicating component

designations and locations. A third mask is a solder resist mask. And fourth, a tape is punched for numerically controlled drilling of the card.

In order to achieve the necessary accuracy, the masks are made at twice the desired finished size and then camera reduced to the proper size. The reduced masks are then used to make silkscreens for printing acid resistant material on the cards. After screening, the cards are acid etched to remove the unwanted metal leaving only the printed wiring circuit on the card.

Using the computer to generate the final artwork, the designer makes a rough sketch of the circuit to be placed on the card. This sketch indicates the placement of components and the routing of the paths. To facilitate coding, the designer usually does the routing of wires on a grid.

To save time in the computer coding process, each component is listed giving a standardized description which is referenced to a drawing of that part. These reference drawings give the component dimensions and pad locations and can be called from the central processor memory when needed. Each component in the list is then coded for position and angle of rotation from the orientation of the reference component. Each pad is then given a number so that a path connection list can be compiled, without knowing the pads' x-y coordinates.

From this input data and a suitable computer program, the same x-y plotter that was used to make sheet metal templates can be used to draw the three masks necessary for making PWC's. This same program and data deck provide the information neces-

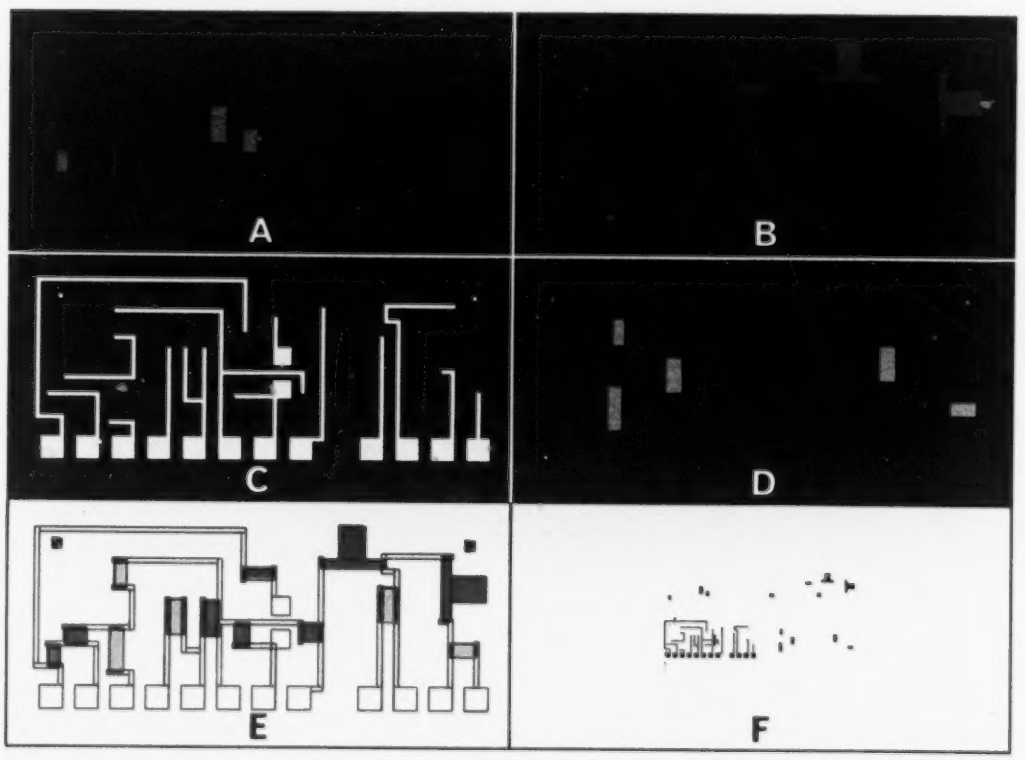

Figure 2. In the production of thick film circuits, mask cutting is done on an x-y plotter (A,B,C,D), a composite mask is also drawn by the plotter (E), and then the masks are photographically reduced to the proper size (F).

sary for punching the tape for numerically controlled drilling of the cards.

One of the most obvious savings experienced using the computer for PWC artwork is that the output from the plotter is to scale; therefore, eliminating the camera reduction step. Updates and changes are easily made to the input data and new photographic masks plotted. The new masks can be plotted on paper if updated drawings are necessary for documentation.

Thick Film Circuits

Computer assistance is provided at two points in the design and production of masks for thick film circuits – ceramic substrates with electronic circuit elements desposited in layers. The computer in conjunction with the plotter, is used to generate the proper resistor shapes for the needed values. These shapes are then plotted on paper as aids to the designer for the final circuit design.

Using these paper aids the designer lays out a separate mask for each layer of the thick film circuit, in much the same way a PWC might be laid out. In order to achieve the required accuracy, the artwork for these masks is drawn at ten times the desired size by a skillful draftsman. Or, using a coding process similar to PWC coding, each layer can be put into a form acceptable for the computer. The computer/plotter combination uses this coded information to produce a mask for each layer of the thick film circuit. These masks are cut five times oversize and reduced down by camera – a savings of 50% in material alone. Registration accuracy for all layers is also guaranteed using the computer technique. Figure 2 shows masks generated by the plotter.

Production

Statistical analysis can be a tedious process, but it can be helpful in checking the quality assurance of incoming parts. When receiving shipments of components such as capacitors, inductors, and crystals a random sample of these items is tested to see how they fall within the specified tolerance range. Using the computer, statistical analysis can be carried out to predict the tolerance variation of the total shipment. From this analysis a decision is made as to accept or reject the shipment. Such a technique saves inspection time and assures fewer system failures caused by components not meeting specification.

If a shipment is accepted, the parts are processed through a computerized inventory system. The flow of all parts

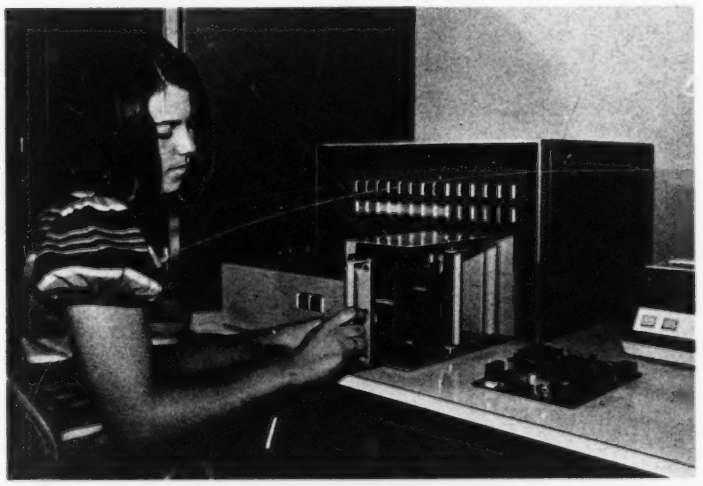

Figure 3. Finished systems are quickly and easily inspected using a computer-controlled test procedure.

and material is monitored by computer. This inventory control system has been designed to show what parts are used in what products and in what quantities, as well as the number of parts available. This same system records the parts as they go into production and as they are returned as subsystems and then total systems.

At this point the finished systems are given a final inspection. Such systems as the GTE Lenkurt 91A PCM channel units are inspected with a computer-controlled test device (see Figure 3). The previous 20-minute non-computer-controlled routine which includes 25 tests takes only one minute with the aid of the computer. If any of the tests performed on the channel unit indicate a problem, the test set begins an automatic trouble-shooting sequence. In order to locate the fault, as many as 75 additional tests may be made, taking only one additional minute. When the fault is located, a printout device records the fault location data on paper tape, and at the same time the failure data is stored in the computer's memory. This information is tabulated in order to discover possible design weaknesses.

System Planning

When a customer wishes to purchase and install a communications system, he sometimes only knows that he wants to get information from one point to another and he does not necessarily know what equipment is required to install this desired communications link.

Computer technology and programming skill has helped to make this information more readily available. For example, microwave site calcula-

PC-220 **GTE LENKURT WEEKLY STOCK STATUS** PAGE 945 WEEK 360

STOCK NUMBER	EXCESS	QUANTITY BALANCE ON-HAND	SCHEDULED	UNSCHEDULED	UNFILLED REQUIREMENT	LEVEL	LEAD MFG LEAD	LEAD CUM LEAD	1ST MFG DEPT	STOCK ROOM	WEEK OF LAST CYCLE COUNT	LAST TRANSACTION	FACTORY AVAILABILITY	YEAR-TO-DATE XXX TOTAL ISSUES	YEAR-TO-DATE XXX SALES ORDER ISSUES	SYSTEM USED ON CODE	CURRENT AVERAGE WEEKLY USAGE	ORDERING FACTORS SAFETY STOCK	WEEKS FROM ORDERING	ORDER POINT QUANTITY	ECONOMIC ORDER QUANTITY	MAXIMUM ORDER QUANTITY	
101 02192 14		1700				756	20	02 00	0	18	58	353	338	144			998	523	131	28	225	1226		2
101 02192 15						710	20	01 00	0	18	58	358	354	144			998	7572				1*		2
101 02192 16						716	20	01 00	0	19	58	356	340	130			998	2476				1*		2
101 02192 19		106				740	20	04 00	0	19	58	356	360	360			998		3		6	29		0
101 02193 01		346				746	20	04 00	0	19	58	346	348	125			998	192	65	11	134	225		2
101 02193 02		244				756	20	04 00	0	18	58	353	353	128			998	39	13	55	27	28		2
101 02395 01		2112				756	20	04 00	0	18	58	355	358	149	2048	2048	998	2158	816	2	1593	2525		2
101 02395 02						716	20	01 00	0	19	58	360	359	125	4000	4000	998	4238				1*		2
101 02395 04						716	20	01 00	0	19	58	310	228	125			998	6				1*		2
101 02395 07						716	20	01 00	0	19	58	351	348	125			998	1421				1*		2
101 02395 10						710	20	04 04	0	19	58	292		268			94					1		2
101 02450 01				1000		740	20	13 00	0	19	58	336	357	333	616	616	93	346	80	12	600	520		2
101 02450 02						710	20	01 00	0	19	58	351	345	125			998	342				1*		2
101 02450 03		645				750	20	01 00	0	18	58	355	323	125			998	110	70	49*	105	910*		2
101 02450 04		847				740	20	04 00	0	19	58	355	322	125			998	38	20	99	34	136		2

Figure 4. Stock status reports provide statistical information used by production control to aid their scheduling of production.

tions can and are being made by computer. By making measurements of the geography of the area, it is possible to determine, for a given transmitter/receiver combination, the antenna placement and orientation as well as such performance information as free space loss. This information must be documented and sent to the FCC for approval before it can be installed; therefore, the sooner it is submitted, the better. All approved installations could be recorded in a central memory system so that any proposed system could be checked against the memory for conflicts.

If it is a cable repeater installation rather than a microwave system that is under consideration, the computer is also of assistance in laying out the communications link. Such information as the system length, the lengths and types of existing cable, and the type of information to be transmitted is fed to the programmed computer which prints out the optimum repeater spacing and the repeater slope and voltage settings. The specified repeater locations are then checked to determine if it is possible to place the repeaters exactly as specified. If not, due to physical obstructions or other causes, the necessary adjusted spacings are fed into the computer which then calculates voltage drops and repeater slope settings to accompany these new spacings. The printout of the spacings and voltage drops and slope settings is used as an installer's document for the proposed system.

Actual system design is also aided by the computer. Using a series of decision tables programmed into the computer, complex systems are optimized for performance and manufacture. Where there are many options available, such a program assures the best arrangement of the system parts and also guarantees consistency of design if the same set of options are ordered at another time. Once the desired system has been designed and laid out, the computer, by searching its master parts list generates a parts list for this particular system.

Paper Work

When a customer places an order for equipment, the computer checks the inventory list to determine what equipment, subsystems, parts, and raw materials are available to fill the order. If the order cannot be filled with the materials at hand, the computer prints out the items and quantities to be built or purchased and a list of vendors and their respective lead times.

Using the inventory information from a computerized production control record (see Figure 4), the customer shipping date is established.

The computer that is used for inventory and production control is also used for accounting and other business applications. It is used for ordering and check writing for paying for materials, billing customers, and writing paychecks. In general, the computer can be and is being used to keep track of the company's assets and liabilities.

Whether it is a routine bookkeeping matter or a tedious statistical analysis, the computer can only do what it is programmed to do and its computations are only as accurate as the data that is fed into it. Therefore, the computer can save time, effort, and money only if the assigned jobs are properly designed and programmed. With this in mind, it is necessary to have personnel familiar with the tasks to be performed and with systems design and computer programming expertise in order to take full advantage of the computer's capacity.

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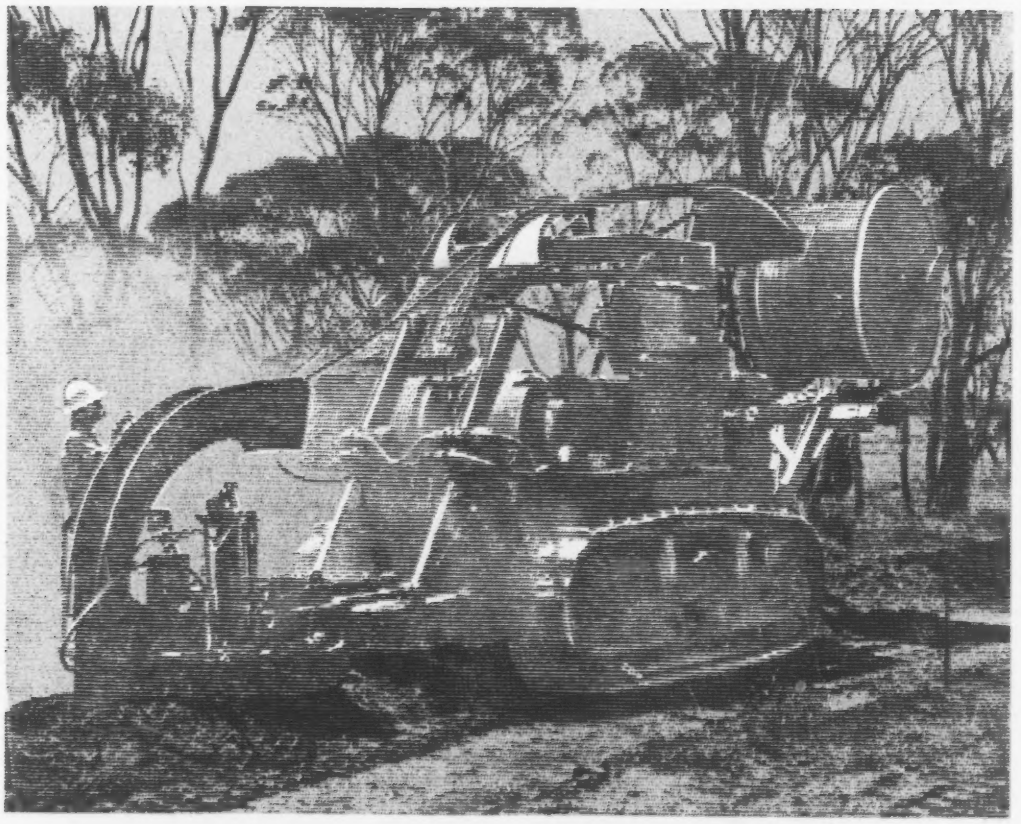
MAY 1971



coaxial communications

Cover photo courtesy of "The Telecommunication Journal of Australia."

Coaxial cable communications can provide short-haul, as well as long-haul, high-density communications facilities.

Over the years, microwave radio systems have become well established as a primary communications network component because of their economy, flexibility, and general availability. In certain applications, these advantages are no longer valid. Therefore, new considerations are being given to cable transmission, particularly transmission via coaxial cable.

A major factor for this interest in coaxial cable in the United States is that congestion in the lower and more desirable frequency bands is making it increasingly difficult to select clear microwave channels for new systems. In areas not suffering from microwave congestion, underground coaxial cables can provide high-density systems with room for expansion.

Radio vs. Cable

Frequently, a microwave system operator will find that a building permit has been granted that blocks one of his metropolitan paths. With microwave frequency congestion increasing, it may be difficult to engineer a radio solution to this dilemma.

The obvious solution to these problems is to select the less congested, higher frequency bands. However, these higher bands impose such restrictions as shorter path lengths due to rainfall attenuation, and more costly equipment, antennas, and towers.

But engineers are still working on systems of the future, which will use frequencies between 18 and 100 GHz and PCM modulation techniques at speeds of 6-600 megabits. It is expected that these systems will be used in applications where the channel densities require sufficient bandwidth to justify the cost per channel on the necessary short path lengths (3-6 miles). But this is still in the future.

Coaxial cable transmission systems, on the other hand, are available and provide short-haul as well as long-haul, high-density communications.

Such coaxial cable systems have been employed in the United States by the Bell System for many years, beginning with the L-1 system; and likewise in Europe by the various governmental entities responsible for the communications network in Europe. Considerations in planning coaxial cable systems must include such factors as right-of-way acquisitions; cost of the cable to be placed; installation expenses, such as earth burial and splicing costs; and lastly, the electronics investment. The initial costs per channel-mile vary widely depending upon the effect of these various factors. But, regardless of initial costs, coaxial systems usually have lower maintenance expenses than their microwave counterparts.

The microwave system and the coaxial system have many basic similarities. Both systems require a means of stacking message channels. This is typically done using the frequency division multiplexing mode, but PCM systems are also under development. In most circumstances, the same channelizing equipment is used for both systems. For example, GTE Lenkurt's 46A radio multiplex system is also used for coaxial cable systems. Slight differences may occur because of specific requirements of the coaxial system.

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Figure 1 shows a typical terminal equipment installation.

Cable Characteristics

Communications coaxial cable provides the two necessary electrical paths by having a solid copper tube for the outer-conductor and a concentric solid copper inner-conductor. Coaxial cables with spaced insulators approach the ideal condition of having the conductors separated by a dielectric of air. The concentric conductors minimize external interference that can affect the information being carried on the inner conductor. These conductor pairs are called "pipes" or "tubes."

The extremely broad bandwidth of coaxial cable is limited by the presently available multiplex equipment to about sixty megahertz. This bandwidth permits up to 10,800 two-way voice channels to be frequency-multiplexed and simultaneously transmitted over a pair of coaxial tubes. However, the effective bandwidth of a coaxial cable is limited by the required gain needed to maintain good signal quality. With different modulation techniques it may be possible to lower the required gain and increase the acceptable bandwidth.

Although a coaxial line will transmit signals down to zero frequency – dc – a higher lower-limit is usually set. This is because the coaxial line does not provide good shielding at low frequencies and because it is difficult to equalize the line at low frequencies.

The upper frequency limit for a given coaxial system is determined by cable dimensions and construction, and permissible attenuation. All of these factors interact; therefore, a compromise must be made to find the optimum upper limit.

The attenuation of a coaxial cable is given by the following:

$$A = 2.12 \times 10^{-5} \; \frac{\sqrt{f}\,(1/a + 1/b)}{\log\,(a/b)}$$

where

A = attenuation in dB/mile
a = radius of inner conductor in millimeters (Figure 2)
b = inner radius of outer conductor in millimeters (Figure 2)
f = frequency in hertz.

This illustrates how frequency and cable dimensions interact with cable attenuation. The attenuation varies directly with the square root of frequency and inversely with cable size.

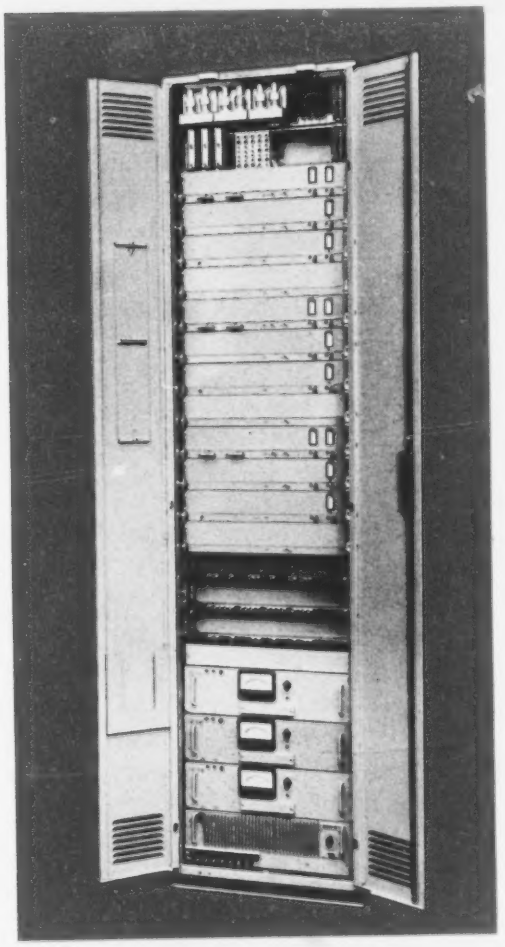

Figure 1. GTE Lenkurt's 46V coaxial cable systems can provide four different capacities – 300 channels, 960 channels, 1200 channels plus TV, and 2700 channels.

Coaxial Equipment

While terminal equipment for microwave and coaxial cable systems is essentially the same, the coaxial line equipment differs for the two systems. For example, in a microwave system, an external power source must be provided at each repeater. But, with coaxial cable systems, the repeaters are powered over the coaxial tube center-conductors; therefore, the repeaters may be located in less accessible areas. For a typical system operated from 24-volt or 48-volt office batteries, the voltage is stepped up to a higher dc potential by means of inverters, and applied to a number of repeaters using constant current regulation. The exact voltage required will depend upon the number of repeaters in series, and with the low-voltage requirements of today's all solid-state repeaters, it is not unusual to have as many as 24 repeaters (with spacings of from 1 - 12 miles) powered from a common power feed.

A nominal value for the attenuation between repeaters is on the order of 40 dB, which will still provide a high signal-to-noise ratio. Both transmit and receive attenuation equalizers are commonly employed to permit wide repeater spacings and still keep the attenuation within 40 dB. This arrangement performs approximately the same function as pre-emphasis and de-emphasis in a microwave system.

In addition to the transmit and receive attenuation equalizers there are "mop up" attenuation equalizers provided on the receive side to correct for any minor irregularities in the response of the cables, or the repeater equalizers on all but the shortest of systems. Pilot stop-filters eliminate any signals at the coaxial pilot frequencies from the multiplex signals to prevent the interaction of the coaxial repeatered-line pilots and the multiplex signal. Figure 3 shows the block diagram of a coaxial cable system.

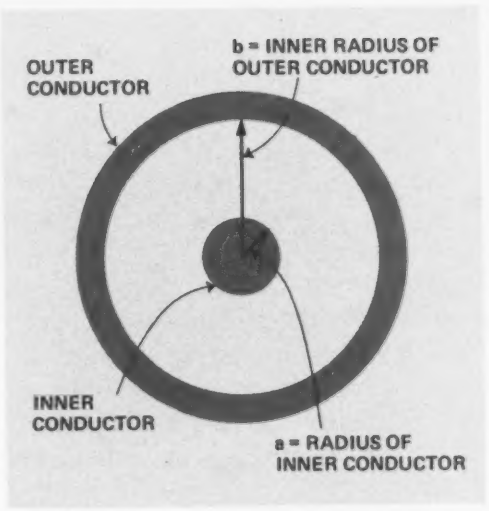

Figure 2. A coaxial pipe or tube consists of two concentric conductors.

Buried System

The frequency response and insertion loss of a length of coaxial cable is a function of the temperature of the cable. The temperature coefficient of coaxial cable is 0.2% per °C, in the carrier frequency range of interest. As the temperature of the cable increases, the attenuation of the cable increases, and it is necessary for the repeater gain to be varied to maintain the proper operating levels for succeeding repeaters and the terminal equipment. In coaxial cable systems this is handled by periodically placed pilot-regulated repeaters. Figure 4 shows the watertight containers for pilot-regulated repeaters.

In the planning of cable systems where the cable temperature varies over wide ambient ranges, it may be necessary to place these pilot-regulated repeaters as often as every other repeater. In conventional systems the placement of the coaxial cable underground reduces the temperature fluctuations and the pilot-regulated repeaters may be spaced further apart with up to six or seven fixed-gain repeaters between the pilot-regulated repeaters.

Some predistortion is usually desirable in these cases, to stay as close as possible to the design operating point for the intermediate fixed-gain repeaters. For example, when the loss is higher than normal, the pilot-regulated repeater makes up for this loss, and also transmits at a higher level, to distribute the deviations from the normal fixed-gain repeaters.

An interesting variation in the control of repeater gain is to have the gain dependent upon the temperature of the repeater. Siemens AG of Munich, Germany, has developed such a repeater which is used in the GTE Lenkurt 46V coaxial cable system. This temperature-dependent repeater employs a semi-conducting element of indium-antimonide in its feedback circuit. By selection of the proper proportions of this compound and doping with nickel-antimonide, it is possible to change the resistance of the semiconductor and thus match the temperature and gain quite accurately. Vernier adjustments are provided for slight variations in repeater spacing. This variable gain repeater automatically matches the gain and temperature

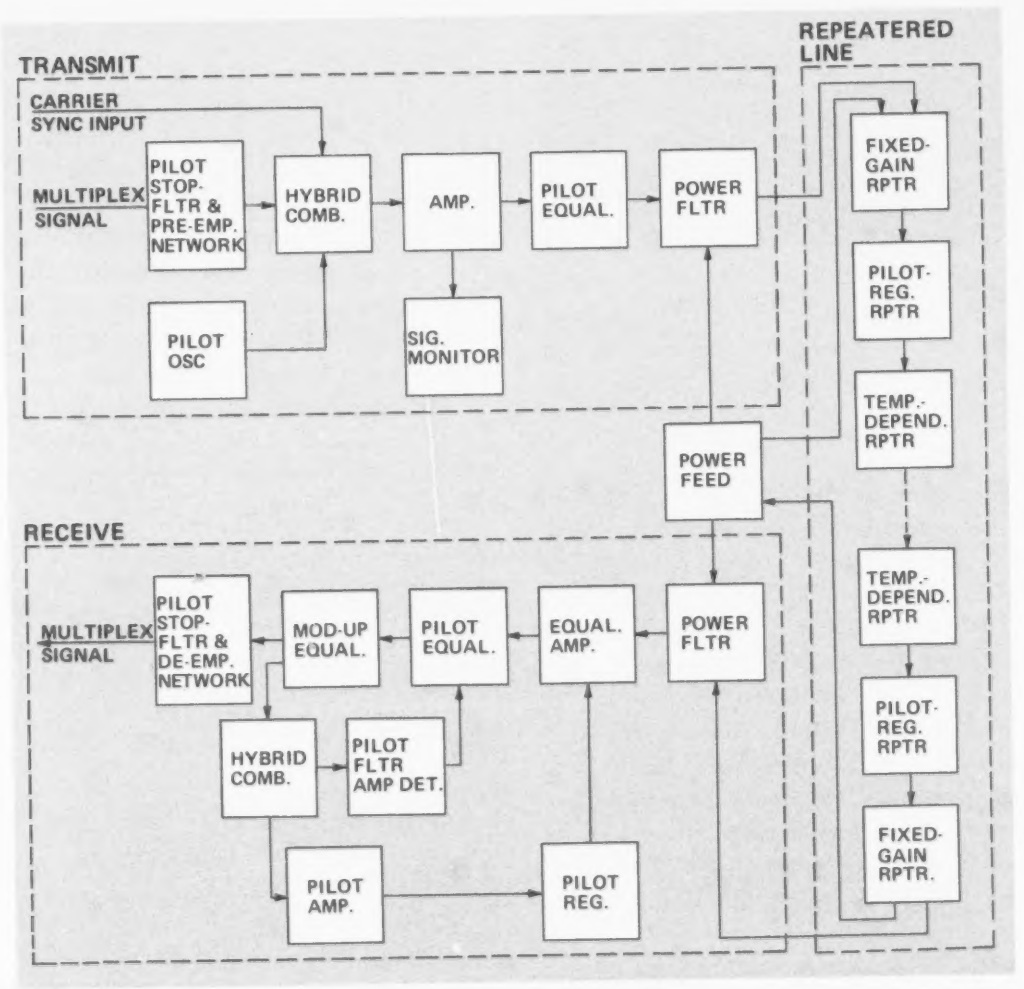

Figure 3. The simplified block diagram of a representative coxial cable system illustrates the functions of the terminal and line equipment.

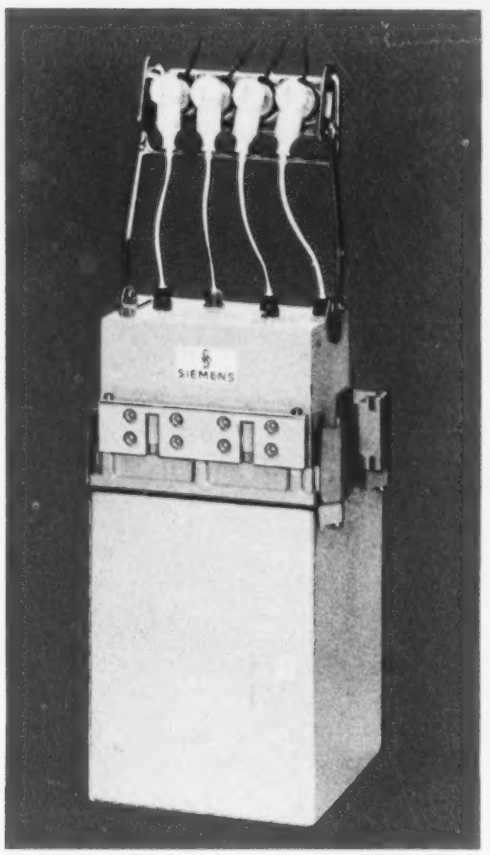

Figure 4. Highly reliable temperature-dependent and pilot-regulated repeaters are packaged in water-tight containers for underground installations.

to maintain proper level stability. These temperature-dependent repeaters have a low power requirement which helps to increase the number of repeaters that can be powered from a common power feed.

Since temperature-dependent repeaters are partially regulating, it is possible to have as many as twelve temperature-dependent repeaters between pilot-regulated repeaters. It is necessary, however, to provide good correlation between the temperature of these repeaters and the coaxial cable temperature.

These temperature-dependent repeaters are outstanding in simplicity and reliability. Only three highly reliable transistors are needed per repeater, and MTBF (Mean Time Between Failures) figures of 500,000 hours per repeater are not unusual. Because of this high reliability, the coaxial cable and repeaters can be put underground without planned access and planned maintenance. Figure 5 illustrates two repeater housings, one with access and one without.

Repeater Spacing

The spacing between repeaters is dependent upon the bandwidth transmitted and the diameter of the cable and associated attenuation characteristic. Standard size coaxial cables can be described in terms of the inner diameter of the outer conductor. Therefore, standard large diameter cable is expressed in inches as 0.375 inch cable, or in millimeters as 9.5 mm cable. Small diameter coaxial cables are described in similar terms as 0.174 inch cable, or 4.4 mm cable. Figure 6 lists CCITT (International Telegraph and Telephone Consultative Committee) channel capacities and repeater spacings as a function of cable diameter.

The small diameter cable (0.174 inch) is generally used where the ultimate growth of the communications

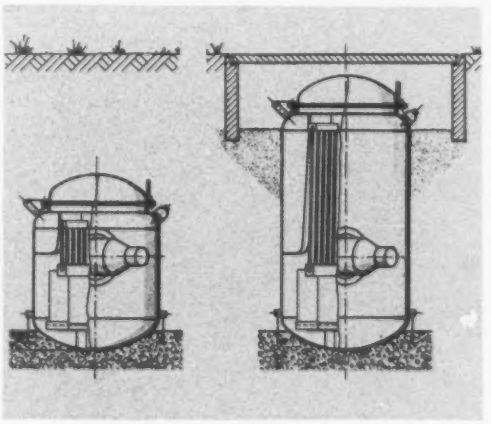

Figure 5. Underground repeater housings are available without access (left) and with access (right).

System Channel Capacity	Repeater Spacing .375 in (9.5mm) cable		Repeater Spacing .174 in (4.4mm) cable	
	Miles	Kilometers	Miles	Kilometers
300	11.6	18.6	5.0	8
960	5.8	9.3	2.5	4
2,700	2.9	4.65	1.25	2
10,800	0.97	1.55	Not recommended	

Figure 6. The CCITT has established channel capacities and repeater spacings for coaxial cable systems as a function of cable diameter.

system can be limited in terms of maximum channelization and system length. Extra cable loss and more frequent repeater spacings cause the noise performance for systems employing 0.174 inch cable to be higher than that obtained with 0.375 inch cable.

A general rule that has been followed is that the communications capacity can be tripled when the repeater spacings are halved. By always cutting the spacings by a sub-multiple for expansion, reuse of existing buildings, repeater housings, and other auxiliary features is possible. This reuse keeps expansion costs down, making the long term investment in coaxial cable more attractive.

Applications

Recent interest in wideband communications has also directed attention to coaxial cable transmission systems. Video-phone, facsimile, and television are some of the areas of communication that are bringing more attention to coaxial cable. In order to provide the necessary bandwidth, higher microwave frequencies can also be used, but there are some transmission restrictions with these higher frequencies (these will be discussed in a future Demodulator article). In metropolitan areas, even if a clear frequency allocation can be obtained, it is not always possible to obtain a transmission path clear of obstacles – buildings, other towers, etc. With coaxial cable, wideband services are not affected by the obstacles experienced with radio transmission, but right-of-way acquisitions may be difficult to obtain.

Communications are increasing efficiency in industrial and municipal operations. The availability of a frequency band of a megahertz or so on a coaxial cable system can offer a sufficient number of communications channels to serve these users' needs for many years in the future. A small size cable without repeaters can provide an extremely reliable, short-haul transmission system. The cost is not great considering the capacity and versatility provided. Applications could include emergency alarm signaling, voice communications, data, and slow-scan television.

The next break-through in coaxial cable transmission will come when equipment for PCM on coaxial becomes readily available. New techniques for cable burial are also rapidly being developed which should lower cable installation costs.

Coaxial cable transmission can provide even better transmission quality and wider channels than microwave systems. So, it may not be long before the user can freely choose between coaxial cable and microwave depending upon which best fits his needs and physical environment.

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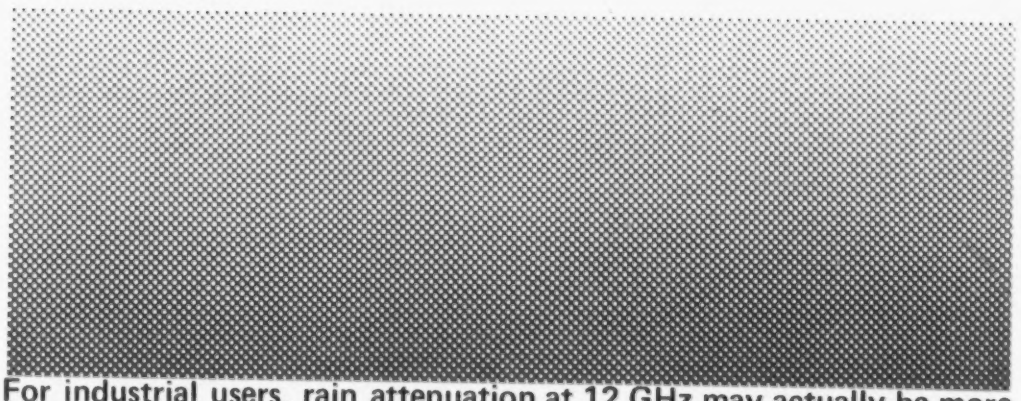
12 GHz

a new look by industrials



For industrial users, rain attenuation at 12 GHz may actually be more benign than other transmission outages. So, shouldn't the industrials use the 12-GHz band?

Most industrial users, for a variety of reasons, have usually selected the two lower frequency bands – the 2- and 6-GHz bands. A review of the FCC frequency listings shows only a few hundred licenses in the 12-GHz band, compared to many thousands in the 2- and 6-GHz bands.

The most common reason for this strong preference for the lower frequencies is the susceptibility of the 12-GHz band to rainfall attenuation. Although the effect is present to some degree at the lower frequencies, it increases rapidly with frequency. And, a rainfall intensity causing only a few dB of attenuation at a lower frequency could be sufficient to cause a path outage at 12 GHz (see Figure 1).

Even without the rain effect, users whose operational experience has been in the lower bands tend to prefer them to a band with which they are less familiar. The availability and cost of accessories such as antennas, waveguides, and test equipment have also been an important factor affecting usage.

A New Look?

Several things point toward a "yes" answer to this question. For example, as more microwave systems come into existence, there is growing frequency congestion and in some areas it is already difficult, if not impossible, to find interference-free frequencies for new systems or paths in the 2- or 6-GHz bands.

RF (radio frequency) channels are licensable with 20 MHz of bandwidth in the 12-GHz band; whereas only 10 MHz are available at 6; and 8 MHz at 2, under FCC rules. Thus, of the three bands, 12 GHz is the best suited for wideband services.

Equipment for the 12-GHz frequency band, including antennas, waveguides, and test equipment, is now widely available, with proven quality and reliability quite on a par with equipment for the lower bands. Experience in the 12-GHz band has shown that the only really important propagation differential is that of the rain attenuation effect.

FCC policy for a number of years has been aimed at promoting increased usage of the bands above 10 GHz. One requirement which has been in effect for some years is that any new systems entirely within a municipal or local area must use frequencies above 10 GHz. The Commission has also sought to encourage use of the 12-GHz band for short spur legs on long systems,

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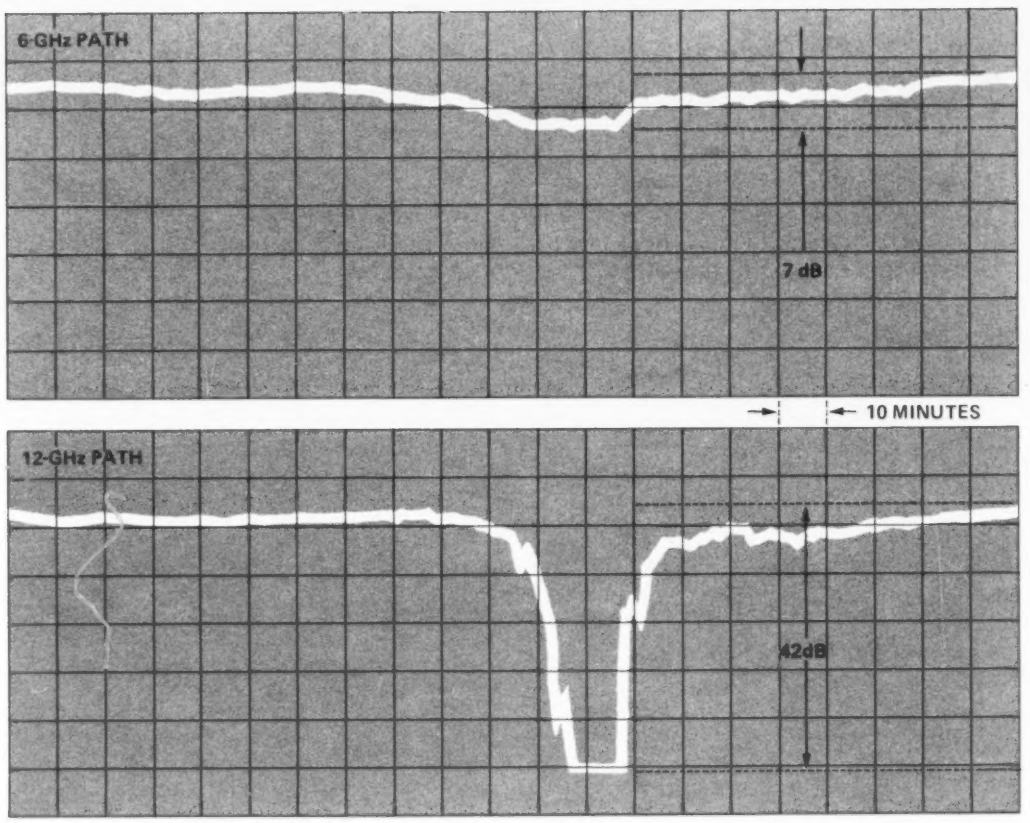


Figure 1. This recording of two simultaneously transmitted channels illustrates the susceptibility of the 12-GHz channels to rain attenuation.

thus keeping the lower frequencies available for backbone routes.

Non-Rain Transmission

Comparing 6- and 12-GHz transmission characteristics under non-rain conditions shows that there is really little difference between the two systems in overall expected performance. For example, on a given path with two given antennas, the path attenuation is greater at 12 GHz than at 6. But, the antenna gain is greater at 12 than at 6. Adding waveguide losses in order to determine end-to-end path loss (path loss plus waveguide losses minus antenna gains) shows the average 12- and 6-GHz systems to be comparable (see Figure 2).

Receiver noise-figures tend to be 1 - 2 dB greater at 12 GHz than at 6 GHz, and for comparable types of equipment there may be from 1 - 3 dB less transmitter output power at 12 GHz than at 6. Thus, with present day equipment, one might expect a given 12-GHz hop to be at a disadvantage of from 2 - 5 dB from the standpoint of equipment. This differential may well be reduced as even better components become available at the higher band.

Path clearance requirements, for a given degree of performance, are slightly lower at 12 GHz than at 6 because the Fresnel zone radius at 12 is only about three-quarters as large as at 6 (see Figure 3). However, this difference is not enough to be signifi-

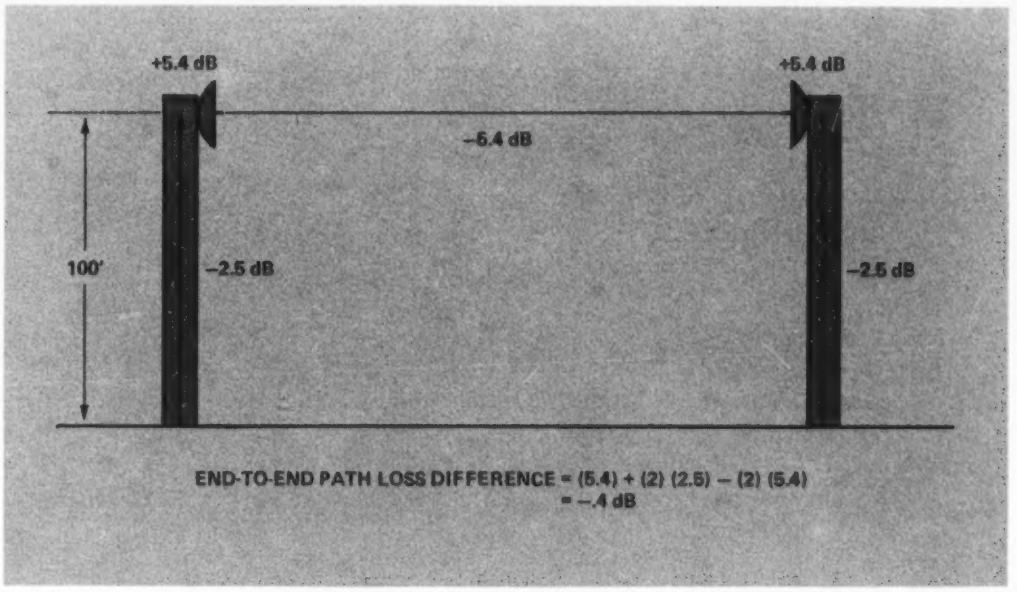


Figure 2. When compared to a 6-GHz system, a 12-GHz system has a similar end-to-end path loss.

cant. Fading of the multipath type is quite similar in nature to that experienced at 6, though it is now generally considered that the fading at the higher frequencies is somewhat greater. Where necessary, space diversity can be used to overcome multipath fading, and the same spacing is even more effective at 12 than at 6 GHz.

Summing up, the total net differential between the 6- and 12-GHz bands is relatively small, and in some cases may even favor the 12-GHz band. Thus, if it were not for the rain attenuation effect, there would be no reason why the 12-GHz band could not be used in much the same way as the lower frequency bands.

Rain Attenuation

Rain attenuation at the higher microwave frequencies has been under study and investigation for more than 25 years. Much is known about the qualitative aspects, but the problems faced by the microwave transmission engineer – that of making quantitative estimates of the probability distribution of the rainfall attenuation for a given frequency band as a function of path length and geographic area – remains an extremely difficult one.

In order to estimate this probability distribution, instantaneous rainfall data is needed. Unfortunately the available rainfall data is usually in the form of a statistical description of the amount of rain which falls at a given measurement point over various time periods – generally at least an hour in length.

The rain-induced attenuation along a given path at a given instant in time, however, is a function of the integrated effect of the rainfall existing at all points along the path and is affected not only by the total amount of water in the path at that instant but also by its distribution along the path in volume and drop size.

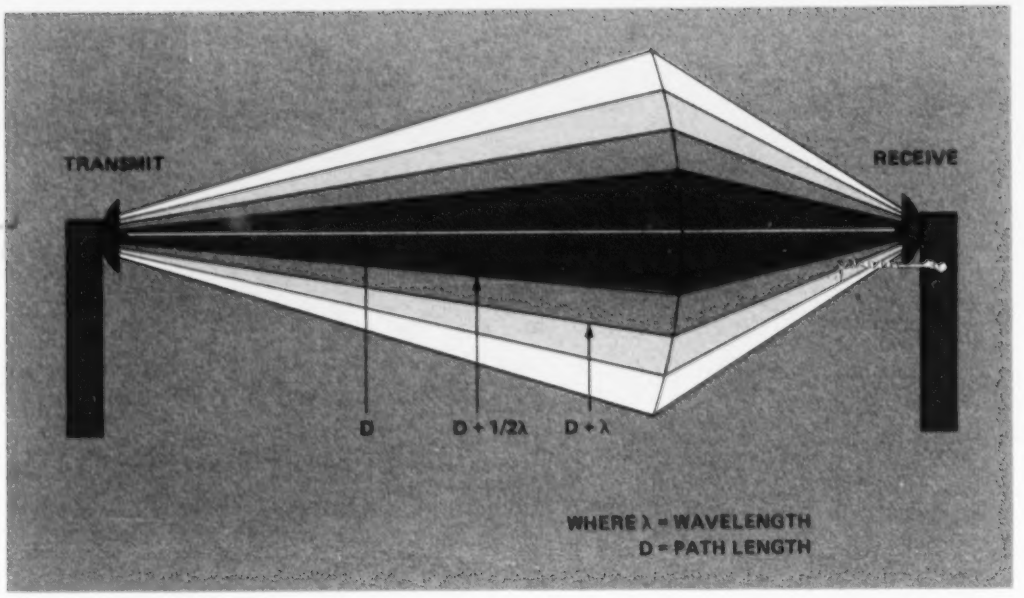


Figure 3. Fresnel zone radii are a function of the signal wavelength, and consequently, the signal frequency.

For heavy rain rates the instantaneous distribution of volume and drop size along the path is highly variable, and is difficult to predict with any sort of accuracy from the kind of rainfall data generally available.

One of the earliest and most comprehensive attempts at developing a workable prediction method was carried out by Bell Laboratories in the 1950's, and was described in a classic paper by Hathaway and Evans (1958)*. In their paper Hathaway and Evans developed a method of predicting annual outages for microwave paths operating in the 11-GHz common carrier band, as a function of path length, fade margin, and geographical area within the contiguous United States.

This study has proved to be a worthwhile prediction tool, and when used with a recognition of its limitations, is still one of the best references available for microwave engineers working within the United States. The Hathaway and Evans method can be modified slightly to adapt it to the 12-GHz industrial band rather than the 11-GHz common carrier band (see Figures 4 and 5).

Increasing fade margin and shortening path lengths are the most readily available tools for reducing the per hop outage in a given area. For fade margins other than 40 dB as shown in Figure 5, correction factors (shown in Figure 6) can be used.

The total annual rainfall in an area has almost no relation to the rain attenuation for the area. Within the U.S., the northwestern states, for example, have the greatest annual rain-

*Other investigations were carried out for the Federal Aviation Administration and are covered by Report No. FAA-RD-70-21, *Rain Attenuation Study for 15-GHz Relay Design*, and Report No. FAA-RD-70-47, *Weather Effects on Approach and Landing Systems.*

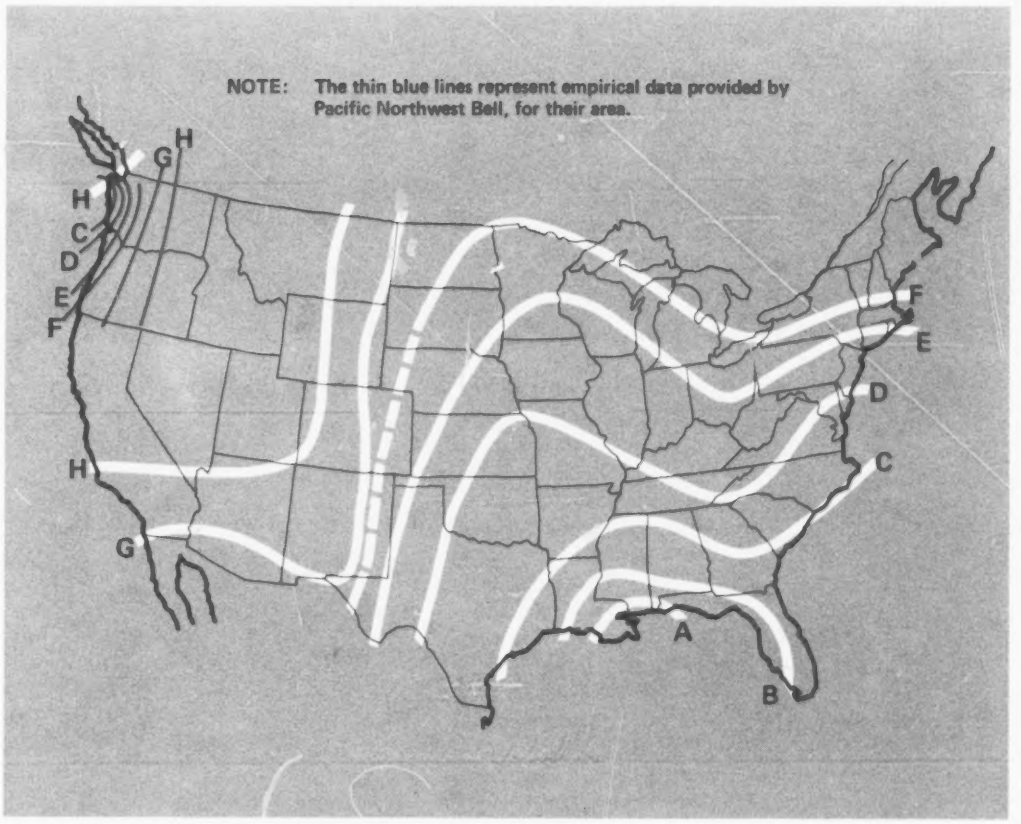


Figure 4. The contours of this map have the same average rainfall distribution and can be used with Figure 5 to predict the effect of rainfall on outage time.

fall, in excess of 100 inches per year, but it is produced by long periods of steady rain of relatively low intensity at any given time. Other areas of the country with much lower annual rates experience types of rainfall such as thunderstorms and frontal squalls which produce short duration rains of extreme intensity, and it is the incidence of rainstorms of this type which determines the rain attenuation characteristics of an area.

Even the rain statistics for a day or an hour have little relationship to the excess path attenuation. A day with only a fraction of an inch of total rainfall may have a path outage due to a short period of extremely high intensity, while another day with several inches of total rainfall may experience little or no excess path attenuation because the rain is spread over a long time period.

Reliability Objectives

A company with its own communications system is the end user as well as the operator of the system, and thus is in a more flexible position than the common carriers who are selling communications service to the public. The private user can meet exact reliability requirements for different parts of a system. For example, a spur leg to a facility of minor importance might be considered satisfactory with a pre-

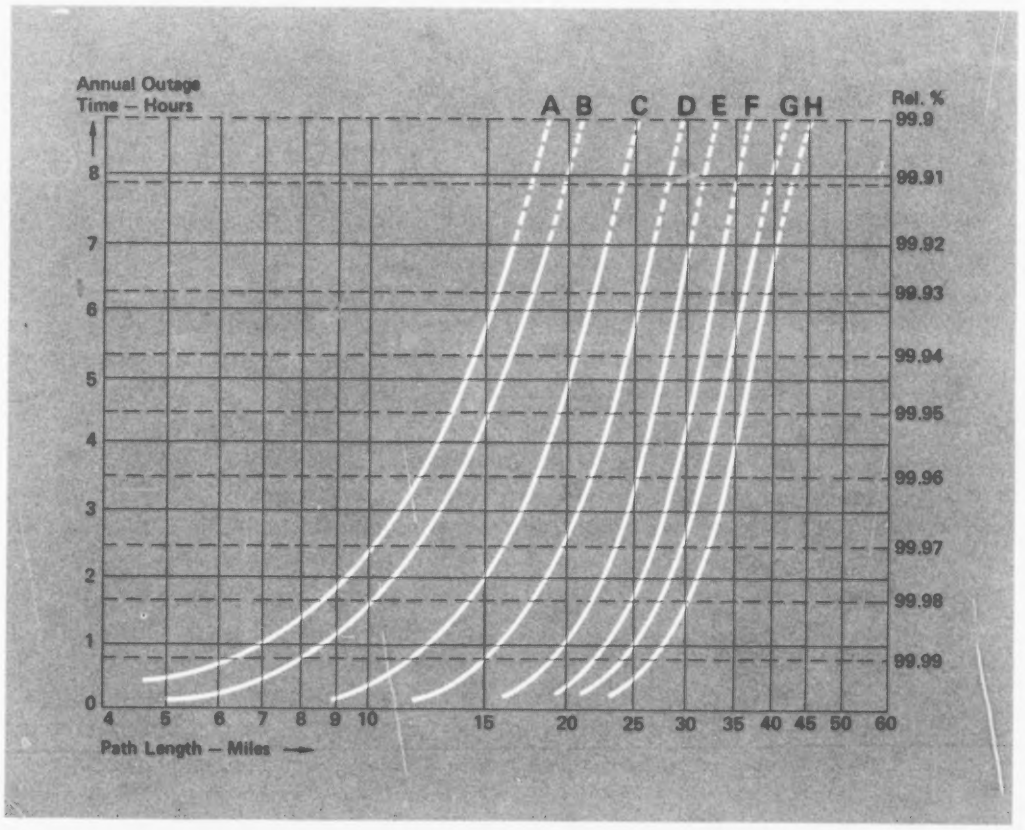


Figure 5. These curves, for use with the contour map of Figure 4, are based on 12-GHz paths with 40-dB fade margins.

dicted outage of several hours per year, in sharp contrast to the requirements for a backbone hop of a long system or into a site of major importance.

Fade Margin	Change annual outage by:
35 dB	+ 20%
45 dB	– 15%
50 dB	– 25%

Figure 6. Using these correction factors, Figure 5 can be adapted for paths with different fade margins.

In considering how to establish realistic outage or reliability objectives, several things need to be kept in mind. A single overall design objective for not more than X hours, minutes, or seconds outage over some period such as a year, is an over-simplification. The character of the particular kind of outage and its effect on the system should be taken into account and perhaps there should even be different objectives for different types of outage.

For example, propagation outages due to multipath fading are usually short. An outage of an hour per year due to multipath fading might represent 1,000 or more individual outages,

averaging about 3 or 4 seconds each. On the other hand, propagation outages totalling an hour per hop due to rain attenuation, on a path with a large fade margin, might consist of four or five individual outages averaging ten to fifteen minutes each. The effects of these two types of system outage would be quite different in nature.

A distinction should be made between communications circuits for which an outage of a few seconds or a few minutes is just a nuisance or an inconvenience, and circuits for which such an outage might result in danger to life, great economic loss, or other catastropic consequences. The suitability or unsuitability of a rain-affected band such as 12 GHz could differ widely for these two situations.

Even if the maximum possible reliability objectives are established and a path or a system is engineered to the full limit of the state of the art, the possiblity of an outage can never be eliminated but can only be reduced to a very low probability. Thus it is imperative to make any ultra-important services as fail-safe as possible against a loss of the communications channel. Therefore, regardless of the degree of reliability, a system should be engineered so that if an outage does occur it can be tolerated or its effects at least kept within reasonable bounds.

It seems that in some cases, perhaps many cases, a somewhat more relaxed attitude might be taken toward rain-induced outages than toward multipath outages or even equipment outages. In several respects such rain outages seem to be somewhat benign in nature. If the fade margins are kept high and the paths are not stretched out too much, even in the less advantageous areas of the country, the number of outages per year should not be very large, and the length of individual outages on a hop should only rarely exceed some two to perhaps twenty minutes.

Furthermore, such outages would occur only with extremely heavy rainfall somewhere along the path, and the conditions when this is likely to occur are usually known in advance and fairly well publicized. This type of outage should be considered tolerable since it occurs rather infrequently, seldom happens without some advance warning, doesn't last long when it does happen, and is self-healing.

For high reliability systems, usually involving long-haul systems with a great many hops in tandem, the per hop objectives may be as stringent as 99.9999% or so, allowing only about 30 seconds outage per year. Short haul systems, up to say ten hops, might have per hop design objectives of about 99.999%, roughly 5 minutes outage per year. Spur legs or single hop systems may be designed for something on the order of 99.99% or about 53 minutes outage per year. Objectives of this kind are typical of those used in the telephone industry, for public service networks. For other situations, and for other types of service, even lower reliabilities may be acceptable, down to 99.9% or about 9 hours outage per year.

Figure 5 shows the predicted annual outages as percentages, and a little study of the numbers indicates that even in favorable areas of the country one would have to use quite short paths in order to get much beyond the 99.99% line (53 minutes per year). Attempts to extrapolate down to the 99.999% or the 99.9999% areas would be subject to great uncertainty.

Using Figure 5 as a guideline, it is apparent that there are few areas where it would be feasible to use 12

GHz as a part of the backbone route of a long-haul system using conventional path lengths, particularly one where requirements are high. On the basis of this data, it seems that the 12-GHz band would be most useful for situations in which the per hop reliability design objectives fall in the range of 99.9% up to at least 99.99%.

Diversity Plans

In the adjacent 11-GHz band, widespread use has been made of cross-band diversity systems, a form of frequency diversity in which one of the frequencies is in the 6-GHz common carrier band and the other in the 11-GHz common carrier band. This combination is a very effective one and can be used in any part of the country without any particular concern about path length. In heavy rain areas the 11-GHz half of the path can be expected to experience outages during heavy rainfall but the 6-GHz path will be only slightly affected. Furthermore, multipath fading is seldom experienced during heavy rainfall so the temporary outage of the 11-GHz path will have no effect on the system unless the 6-GHz path fails during this time because of equipment trouble, a very low probability situation in well engineered systems.

Cross-band diversity between the 6-GHz and 12-GHz industrial band is technically feasible and would be equally useful. But under FCC licensing policies in the industrial bands, cross-band diversity is only available in special cases where a definite need can be demonstrated. Also its use would not result in any reduction in the 6-GHz band usage, since industrial users are not allowed to use in-band frequency diversity.

There are a few cross-band hops in the industrial band, and Figure 1 is a recording from one such path, showing an example of a rain outage on the 12-GHz half of the path. This is quite typical of the rain induced outages in the higher bands, both in depth and length. The excess attenuation of the 12-GHz side exceeded 40 dB for a period of about 12 minutes, bottoming the recorder. The actual depth may have been considerably greater than 40 dB. During the same interval, the 6.7-GHz path experienced only a small amount of rain attenuation – about 7 dB at the maximum and of no real significance to the system.

This particular path is about 21 miles long, but the appearance of the attenuation event indicates that it was probably caused by a single rain cell occupying a relatively small portion of the path, rather than by uniform rain spread all along it. This leads to the conclusion that the event might have occurred, in about the same magnitude, even if the path had been quite short, perhaps even as short as five miles. However, the number of such events which would be expected to occur over a given period of time in a five mile path would be only one-fourth the number which would be expected to occur in a twenty mile path. In other words, it seems likely that for paths over about five miles it is not the amount of excess attenuation which determines path length, but rather the number of expected outage events and the total length of the expected outages.

Another approach to a high-reliability system uses a combination of very short path lengths plus route diversity to defeat the rain attenuation problem. These path lengths are from 2 to 5 miles, so the number of repeaters would be large compared to conventional microwave systems where the hops average something like 25 - 30

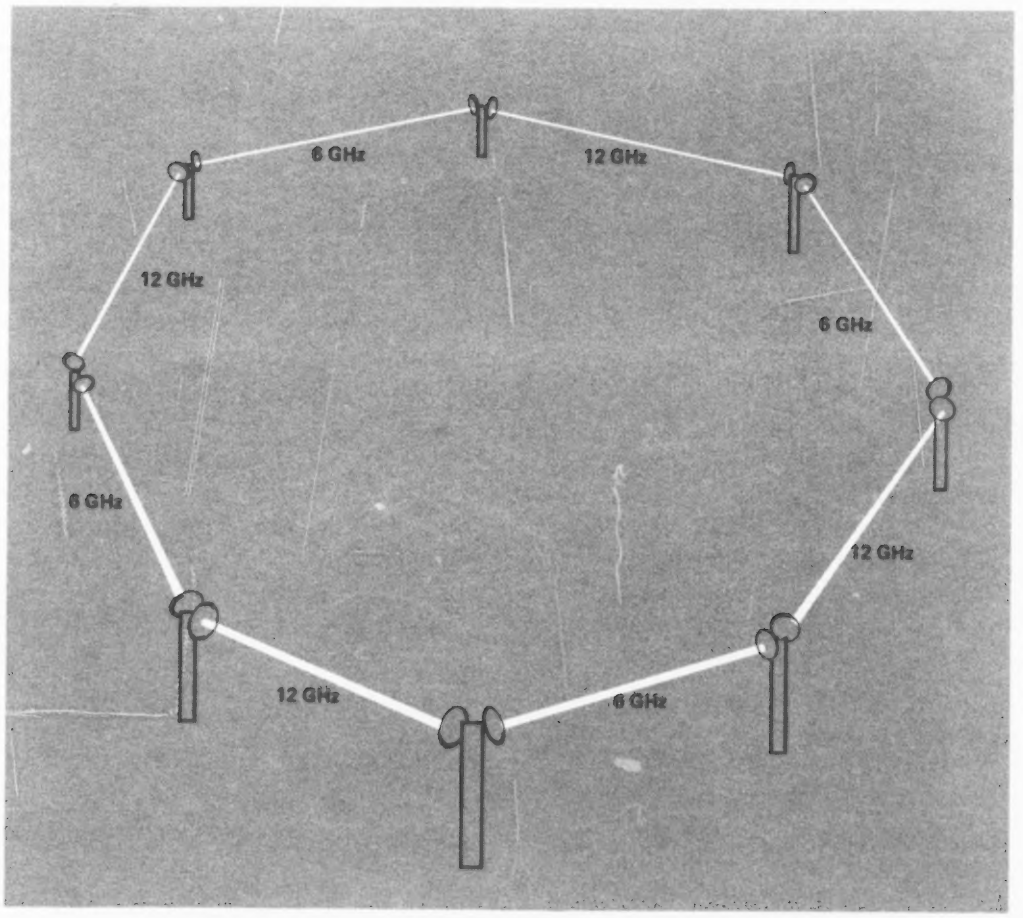


Figure 7. If one link of a closed loop network fails, a loop diversity arrangement will reverse the transmission direction to complete the transmission path between terminals.

miles in length. A system of this kind is called a "pole line radio." For such an arrangement, repeaters must be low in cost, highly reliable, virtually maintenance-free, low in power consumption, and capable of being placed in an inconspicuous housing at the top of some sort of simple pole structure. In addition the repeaters must be broadband to allow high channel density and each repeater must introduce a low amount of distortion and noise. The latter effect would be achieved by using PCM transmission for the system, with regeneration at sufficient intervals along the line to keep the error rate at the desired low level.

This whole technique, though promising, is still in the experimental stage and its potentialities and problems are still largely unknown. One basic principle is that it would require new frequency bands, not already in use by systems with conventional techniques, since the integration problems between the old and new would be large.

For the industrial user there is little likelihood that systems of this type would come into use in the 12-GHz

band, though eventually, there may be something of the kind at a higher frequency.

However, there is one special situation in which a form of route diversity is already being used by some of the industrials. This is the so-called "loop system" in which a microwave system is laid out in the form of a closed loop with some sort of automatic sensing and switching system (see Figure 7). With such a system an outage or failure in any link will reverse the transmission direction around the loop.

Since the evidence indicates that intense rainfall at a given instant is unlikely to occur at two widely separated points, it seems that in such a system it would be quite feasible to use 12-GHz and 6-GHz frequencies alternately around the loop. With no two 12-GHz paths adjacent to one another, the physical separation would seem more than adequate to insure that rain outages would be essentially non-correlated and the likelihood of two paths being out simultaneously would be small.

Unfortunately, most communications systems proceed in more or less a straight line and are thus not adaptable to loop systems, so the possible application is somewhat limited. One possible application would be for systems connecting off-shore drilling platforms, which often are located in a manner suitable for looping. Another would be power companies, whose grid-type power transmission networks tend to be arranged in natural loops.

It should be kept in mind that loop systems, though extremely useful against outages which are relatively rare and rather lengthy, do not provide any protection against rapid, short fading of the multipath type. Where this type fading exists, per hop space diversity should be used to combat it, even with a loop system.

Gain from Experience

The adjacent higher frequency band, from 12.7 - 13.5 GHz, assigned to television auxiliary stations, has had rather widespread usage, a good part of it in microwave relay systems serving CATV systems. For this type of service somewhat lower reliabilities are deemed acceptable, and the systems are generally engineered with little or no regard for possible rain outage, even in the less favorable areas.

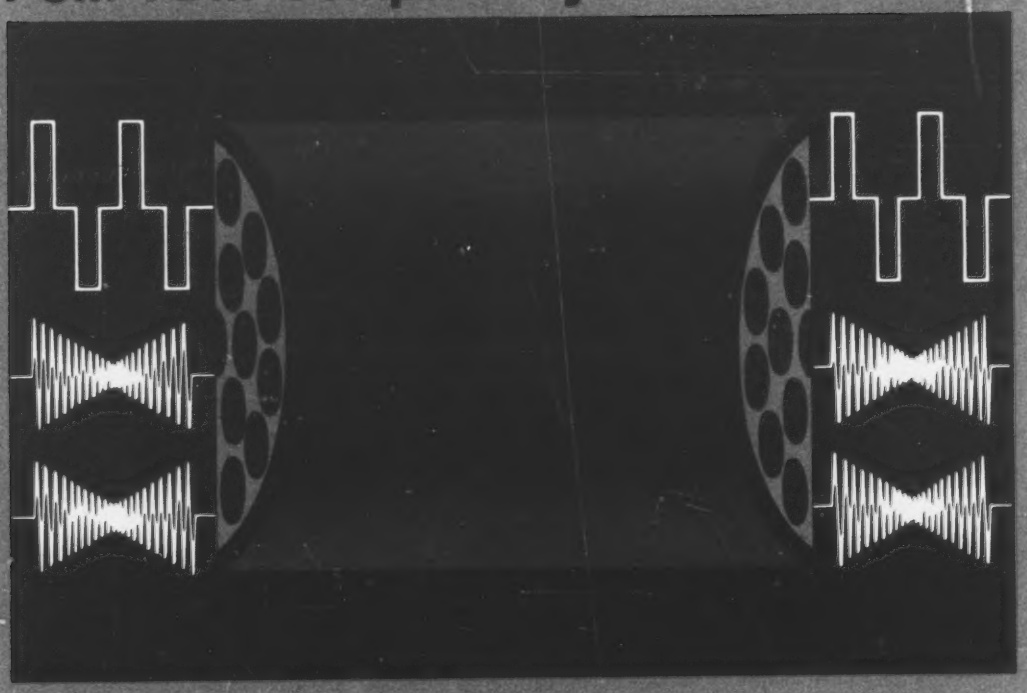
In some areas the common carriers and some of the industrial users have found themselves pushed into the higher frequency bands by congestion in the lower bands, and have generally found that although considered totally unsatisfactory before, the higher frequency bands can be quite useful.

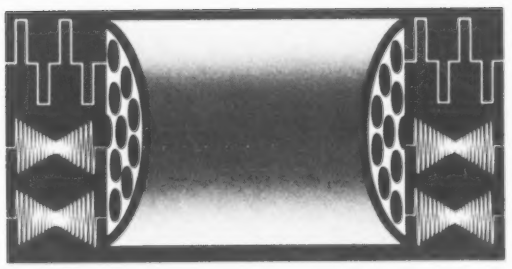
GTE LENKURT

DEMODULATOR

JULY 1971

PCM-FDM Compatibility Part 1





Under certain conditions, pulse code modulation cable carrier systems are compatible with frequency division multiplex systems on cable pairs within the same cable sheath.

It has been the practice in the communications industry to avoid placing pulse code modulation (PCM) and frequency division multiplex (FDM) systems in the same cable sheath. The reason for this taboo stems from the fact that the signal level on a PCM system is so high in comparison to that of an FDM signal that indiscriminate mixing of the two systems may result in rendering the FDM system partially or totally useless. Nearly all noise and crosstalk between the two systems is unidirectional, from the PCM system to the FDM system. The performance of a PCM system will hardly ever be affected by the presence of an FDM system on the same cable.

Because there are economic as well as convenience advantages to the user in combining PCM and FDM systems within the same cable sheath (whether for a temporary or extended period), tests have recently been conducted at the GTE Lenkurt laboratories on the problem of PCM-FDM compatibility. The preliminary results of these tests and the tentative ground rules that have been subsequently established may serve as a guideline to the user who is comptemplating a combination of PCM and FDM systems in the same cable sheath.

Why Combine PCM and FDM?

There are several instances when a user of cable carrier systems may desire to operate PCM and FDM systems over cable pairs within the same cable sheath. For example, he may want to gradually phase out an existing FDM cable carrier system and convert to PCM circuits over a cable route. Or, he may want to install PCM systems on a cable which already has FDM carrier in it to avoid the expense of installing new cable. The FDM carrier, in this case, may include subscriber carrier, N-type carrier or exchange carrier systems.

There may be many cable pairs in one cable and although the metal sheath that encompasses them provides protection from external interference, interference generated within the cable by some of these pairs may cause noise which degrades the quality of the intelligence being conveyed on other pairs.

It is important to realize that the PCM line signal of all 24-channel, T1-type, U.S.-manufactured PCM systems using D1-type channel banks look identical. Also, all D2/T1-type line signals look identical to each other (even though they are slightly different than D1/T1-type signals). Therefore, if one manufacturer can mix PCM and FDM systems on a cable, any other can also. The references to D1- and D2-type systems in this discussion imply particular types of 24-channel PCM terminals (channel banks) both of which are often used in combination with the T1-type repeatered line (regenerative repeaters and associated equipment).

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PCM-FDM Possibilities

Whether it is possible to operate a PCM system in the same cable sheath with one or several FDM systems is determined by the crosstalk coupling loss between the cable pairs involved. Given a certain crosstalk coupling loss in a cable between the FDM cable pairs and the PCM cable pairs, compatibility then depends on the frequency range of the FDM system, the baseband frequency of the FDM channels equipped, the number of PCM systems involved, the length of exposure (in terms of number of FDM repeater sections), kind of FDM system (modulation method), and the permissible amount of performance degradation allowed in the FDM system due to PCM carrier interference. When all of these factors are considered, they are evaluated against the power distribution in a T1-type PCM signal as a function of frequency (the power spectrum). What that power spectrum looks like is of vital importance when PCM-FDM compatibility is evaluated. The highest frequency slot in the FDM system will always be the one of most concern, since it will be the slot most vulnerable to interference from the PCM signal.

As a general rule, interference into the FDM carrier system can be reduced by equipping only the lower-frequency channels in the FDM system. Therefore, when phasing out an FDM system which must operate for some time on the same cable sheath with PCM, the higher FDM channels should be phased out first. The power spectrum components in a PCM line-signal drop sharply below 96.5 kHz, and interference into FDM systems below that frequency is usually negligible. The point of maximum power in a T1-type PCM power spectrum occurs at approximately 710 kHz for busy hour conditions. The maximum PCM power, in this case, indicates the maximum amount of interference that threatens the FDM system.

Cable Characteristics

The achievable crosstalk coupling loss between two cable pairs increases with the number of cable pairs in the cable sheath. This is because there is increasingly less crosstalk coupling in proportion to the physical distance between pairs.

The actual value of crosstalk coupling loss between two cable pairs depends upon which splicing groups have been selected, the splicing methods used, and the general crosstalk characteristics of the cable (such as cable gauge and dielectric insulation material).

Direction Coordination

A PCM repeatered line laid out for one-cable operation has a minimum near-end crosstalk (NEXT) coupling loss requirement between its two directions of transmission. Failure to meet this requirement may result in interference between the two directions. Such systems are often planned with the pairs for opposite directions of transmission assigned to nonadjacent splicing groups (see Figure 1). It is therefore important to keep the FDM pairs protected against interference from either direction of transmission of the PCM system. However, PCM to FDM interference between cable pairs belonging to the same direction of transmission is not nearly as serious as interference between pairs belonging to opposite directions of transmission. The reason for this is that the difference between the signal level on a PCM cable pair and that of an FDM signal on another pair, is at most points along a cable, greater for opposite directions of transmission than between pairs for the same transmission direction. The crosstalk disadvantage is thus greatest between cable

pairs for opposite directions of transmission. Figures 2A through 2C show the near-end, and far-end crosstalk (NEXT and FEXT) characteristics for different directions of transmission in various systems. It is assumed that all FDM system repeaters coincide with repeater locations of the PCM system. One repeater section of the FDM system may correspond to one or several repeater sections of the T1-type PCM system.

The only NEXT paths of significance between the T1 and N3 carrier systems shown in Figure 2C are the ones indicating near-end crosstalk over repeater section 3. The contributions from the other two repeater sections arrive at the FDM repeater greatly attenuated and can be neglected. Therefore, this cause can be treated as if all the near-end crosstalk on this FDM repeater section originated on the T1-type repeater section adjacent to the FDM repeater input.

Likewise, FEXT coupling between T1-type carrier and N carrier is due almost totally to the FEXT coupling over the T1-type repeater section adjacent to the FDM repeater input.

If a PCM system shares a cable with an FDM system for a distance comprising more than one FDM system repeater section, the interference will add up on a 10 log k basis, where k is the number of FDM system repeater sections exposed to PCM interference.

The number of interfering PCM systems also has an influence on the determination of required crosstalk coupling loss, since the noise powers add up. If the number of PCM systems is n, and 10 log n is used to account for the number of systems, the assumption is then made (conservatively) that the PCM disturbers all interfere with the FDM system at equal coupling losses.

Each PCM system engineered for one-cable operation interferes with each FDM system both by way of near-end and far-end crosstalk. Since such a cable system has the pairs for both transmission directions inside the same cable sheath, the interference into each direction of transmission of an FDM system thus originates from both transmission directions of each PCM system (two cable operation implies that both directions of transmission are assigned to pairs contained within separate cable sheaths).

Considering that a one-cable PCM system should be engineered with pairs for opposite directions of transmission in different binder groups (often non-adjacent in the cable), in some cases one type of crosstalk (near-end or far-end) may dominate over the other. In other cases, it may be necessary to conservatively assign half of the crosstalk contribution to each type of crosstalk, when estimating minimum crosstalk coupling loss between PCM and FDM cable pairs.

The ideal condition is when the FDM systems are assigned to pairs in a

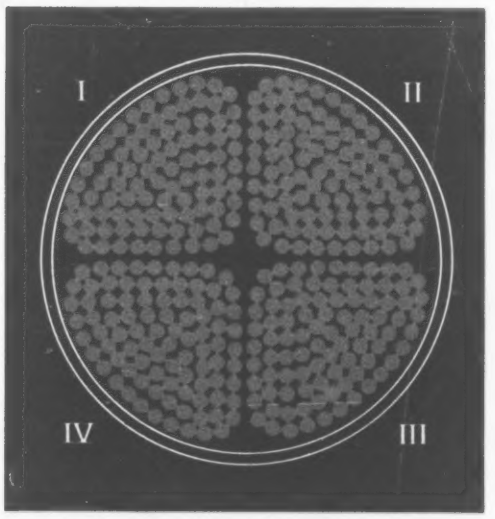
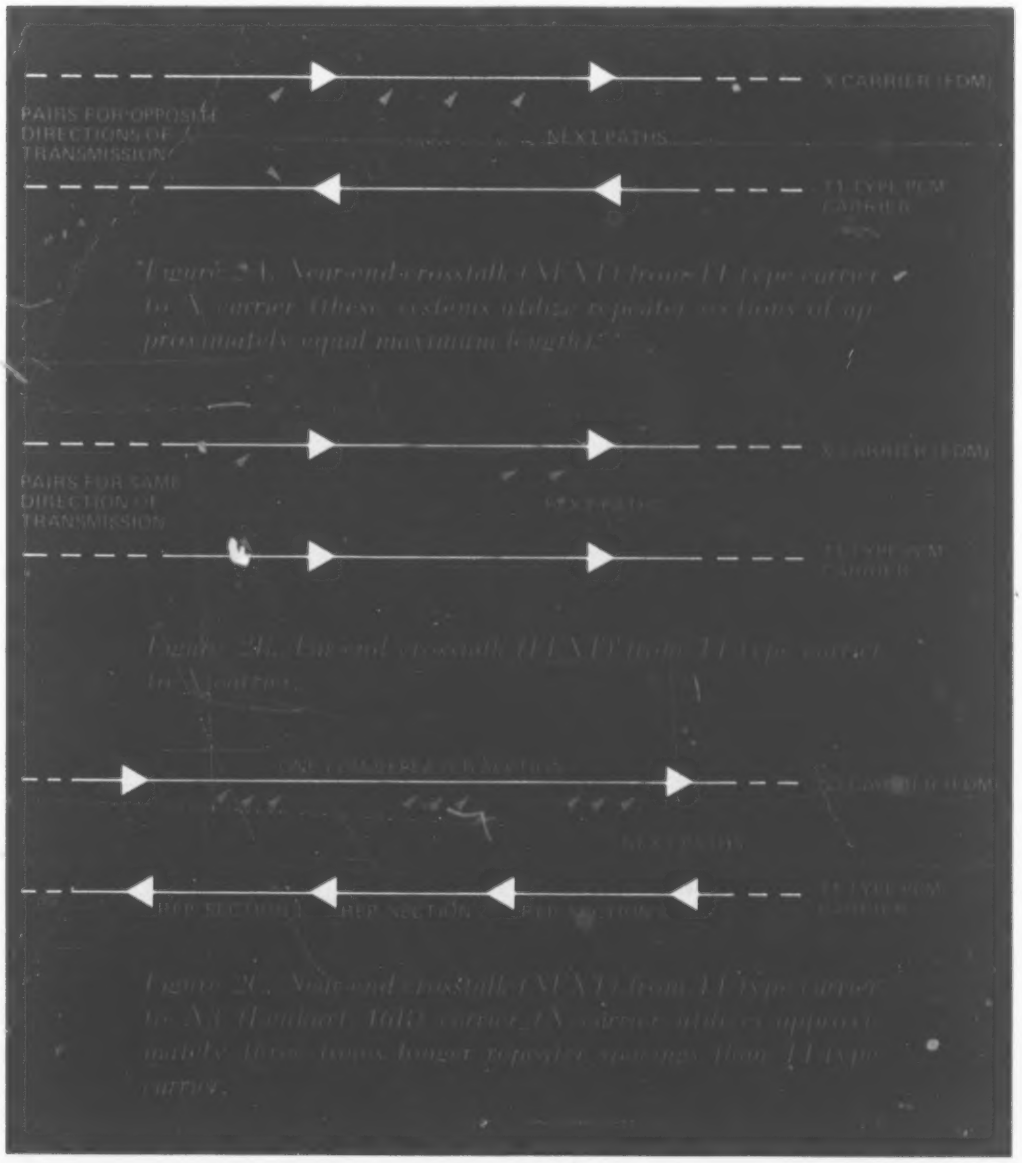


Figure 1. A cable divided into four binder groups. At a splice, if group integrity is maintained, I and III, II and IV, are still non-adjacent beyond the splice. Also, I and II, IV and III, are still adjacent beyond the splice.

splicing group or unit in the cable which lie nonadjacent to any of the two groups or units used for the two directions of transmission for the PCM carrier. If this is not possible, direction-coordination should then be considered. This implies that the two directions of transmission of the FDM system be coordinated with the PCM carrier pairs in such a way that pairs belonging to the same directions of transmission for the two types of systems are assigned to the same splicing group or unit in the cable.

Screen Separation

Several manufacturers of multi-pair cable have developed an internal screen which allows separation of cable pairs into two compartments. This screen is intended to provide electrical partitioning between pairs used for opposite directions of transmission, thus reducing near-end crosstalk in PCM systems. This offers an opportunity for direction coordination, if FDM systems are to be transmitted over such cable along with PCM systems.



It has been suggested by one manufacturer of screened cable that the screening concept may be found useful for providing isolation between PCM and FDM systems. For example, two screens could be provided, dividing the cable core into three compartments, two for PCM and one for FDM usage.

The PCM Power Spectrum

Aside from the observation of direction-coordination between cable pairs, other important factors must be taken into consideration when investigating the possibility of combining PCM and FDM systems in the same cable sheath. What these factors are, and the nature of their potential disturbing effect, may determine whether or not compatibility between the two systems is possible.

A unipolar pulse is shown in Figure 3. It represents a pulse such as it appears in the terminal equipment or in a regenerative repeater before the conversion to a bipolar format has taken place. It is an idealized pulse in that rise and fall times as well as aftershoot have been neglected. The duty cycle of the pulse train is 50 percent. This means that a unipolar string of binary ones in a terminal with a period T has a pulse width of T/2.

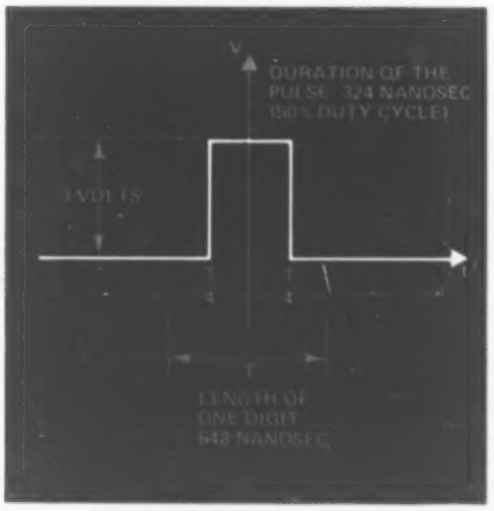


Figure 3. Unipolar pulse.

On a working D1/T1-type system with 24 voice channels carrying traffic, pulses occur randomly and with a pulse density closely approaching 0.50. That is, over a long enough period of time the number of binary ones and zeros (pulses and spaces) tend to be approximately equal. On a D2/T1-type system, pulses will tend to occur with a density somewhat greater than 0.50 (0.55 to 0.65 for busy-hour condition).

Before application to the transmission line, the pulse train is converted to a bipolar format by inverting every other pulse to opposite polarity (see Figure 4). The purpose of this inver-

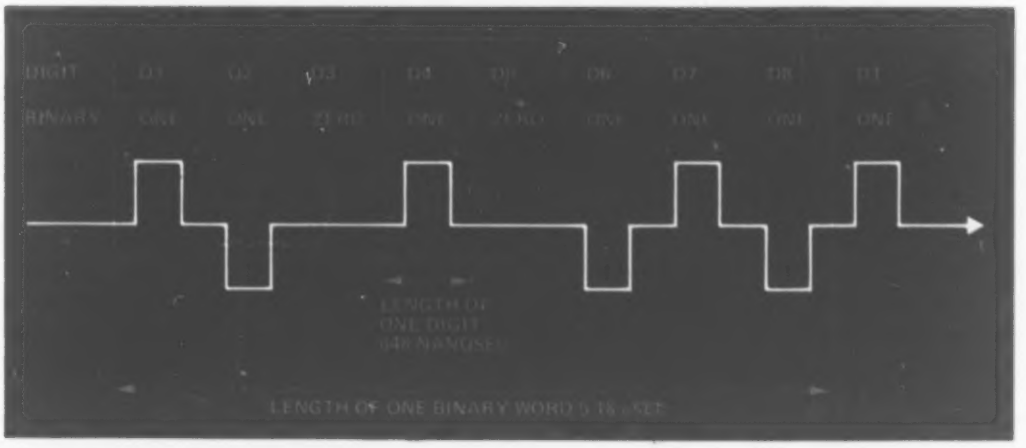


Figure 4. Bipolar pulse train.

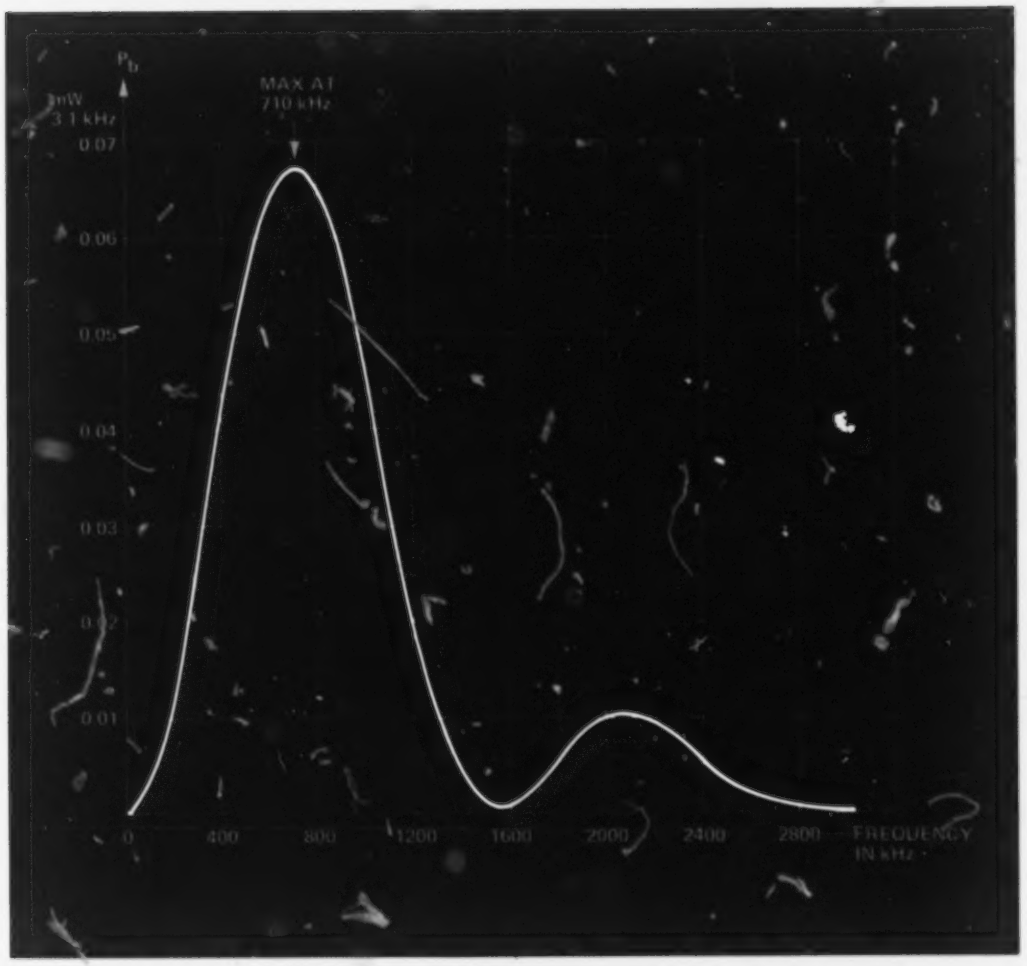


Figure 5. D1/T1-type power spectrum during busy-hour conditions.

sion is to shift the power spectrum to lower frequencies and to remove the dc component of the line signal.

The bandwidth usually available for transmission of voice information in most channels is 3.1 kHz. The random bipolar pulse train has its power distributed (in mW per 3.1 kHz slot) as a function of frequency as shown in Figure 5. This power spectrum is for a D1/T1-type PCM signal as it would appear during traffic conditions at the output of a regenerator. The curve represents the statistical average during traffic conditions and is not valid during idle or on-hook conditions. (The power spectrum during idle or on-hook conditions will be discussed in Part II.)

When PCM and FDM are combined within the same cable, the PCM power spectrum curve of Figure 5 will play an important part in evaluating crosstalk coupling between the two systems.

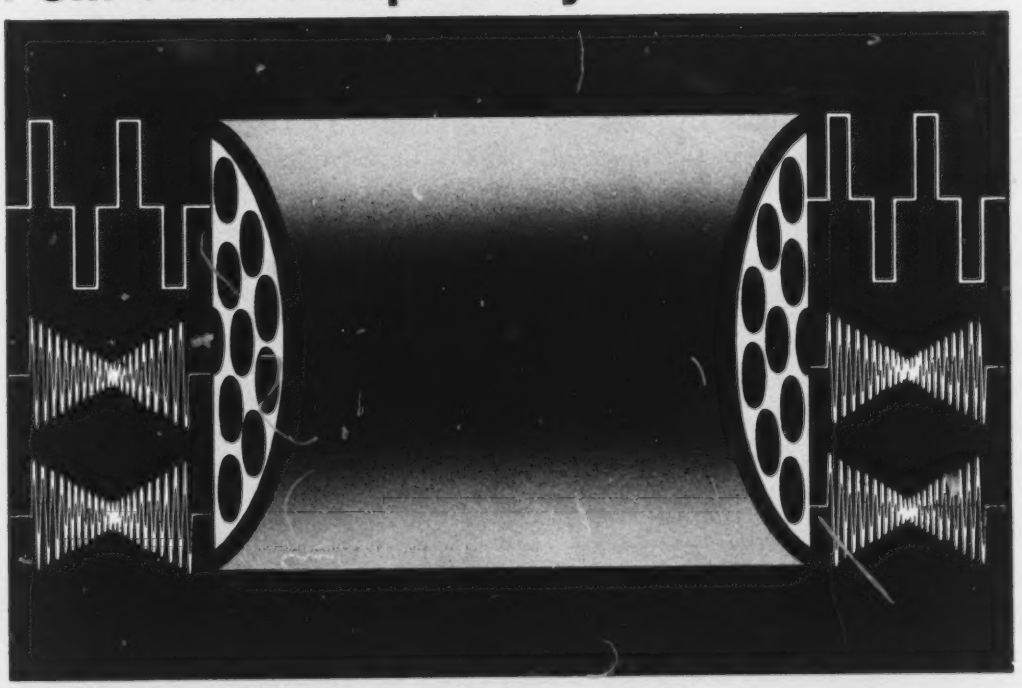
While this discussion of PCM-FDM compatibility has so far been of an empirical nature, Part II will investigate such factors as the PCM power spectrum and its effect on FDM systems, the effect of various types of PCM signaling on FDM, effects of idle/on-hook conditions and a method of estimating minimum crosstalk coupling loss.

GTE LENKURT

DEMODULATOR

AUGUST 1971

PCM-FDM Compatibility Part 2



The GTE Lenkurt study of PCM-FDM compatibility has yielded useful data in a quantity such that it will require three issues to cover all the information instead of the aforementioned two issues. Part II will deal with the theoretical aspects of PCM-FDM compatibility while Part III will apply these theories to a practical analysis of compatibility using a hypothetical PCM and FDM combination.

In the July issue (PCM-FDM COMPATIBILITY, PART I) of the Demodulator, the focus of attention was mainly on how to use to best advantage the empirical information thus far accumulated by GTE Lenkurt in the study of PCM-FDM compatibility. This included information on direction coordination of cable pairs within the same cable sheath and a discussion of the effects of far-end and near-end crosstalk on an FDM system.

This issue goes one step further in guiding the user toward achieving compatibility between PCM and FDM systems which lie within the same cable sheath.

Sampling, Quantizing and Encoding

The sampling, quantizing and encoding into digital form of an analog signal are the three major functions of a PCM terminal. The information used in this discussion is based on the sampling, quantizing, and encoding scheme used in the GTE Lenkurt 9001A, 9001B (both D1-type) and 9002A (D2-type) PCM channel bank assemblies. These assemblies are end-to end compatible with the Western Electric D1 and D2 channel bank assemblies and to similar terminals produced by other communications equipment manufacturers; hence the designation, "D1- and D2- type."

The level at which a voltage sample is quantized is relevant in evaluating PCM-FDM compatibility and is particularly important at the lower voltage levels since this is where the power spectrum may sometimes be confined to discrete frequencies during quiet and idle conditions in the PCM terminal. An "idle condition" implies that the telephone receiver may be on or off the hook and that no message is being transmitted even though there may be a line open between two parties.

In D1-type systems, each voice frequency channel is sampled 8000 times per second and each voltage sample has 127 discrete voltage levels available for quantization. The zero voltage level is known as level 64. There are 63 levels above level 64 in the positive direction, and 63 levels below level 64 in the negative direction. The number of the quantization level nearest the level sampled is encoded into a sequence of binary pulses and spaces, a pulse corresponding to a "one" and a space to a "zero". Figure 1A gives an example of noise or of low-level voice

NOTE:
The back cover of this issue contains errata for the GTE Lenkurt publication, *Engineering Considerations For Microwave Communications Systems.*

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signal sampling and also shows a portion of the level structure of a D1-type PCM system. Figure 1B shows examples of pulse patterns on the line. It should be noted that as the levels get further away from zero (level 64), the steps become progressively larger. This is because most of the information in speech signals is concentrated at low amplitude levels and small quantum steps are thus needed more at the low amplitude levels than at the higher levels in order to maintain a reasonably constant signal-to-noise ratio (in-

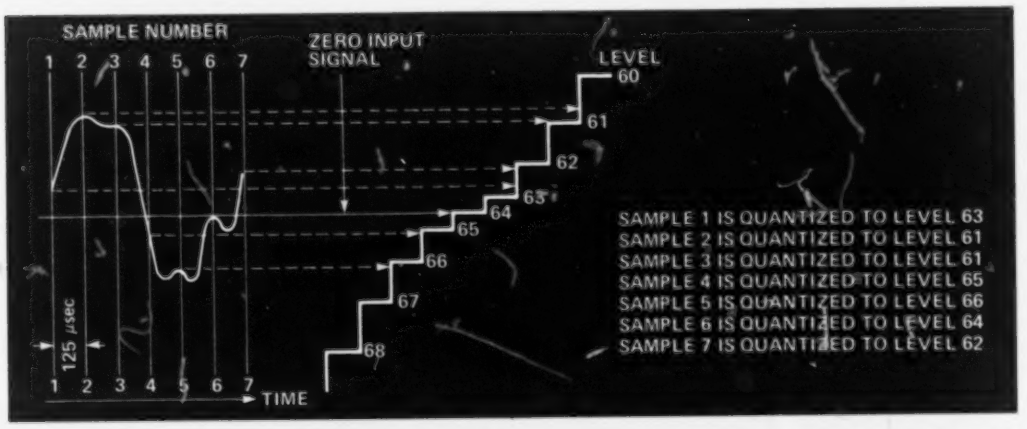

Figure 1A. In a D1-type terminal, each voltage sample is quantized (rounded off) to one of 127 possible levels. The number of the quanitzation level chosen is transmitted to the line as an encoded binary word.

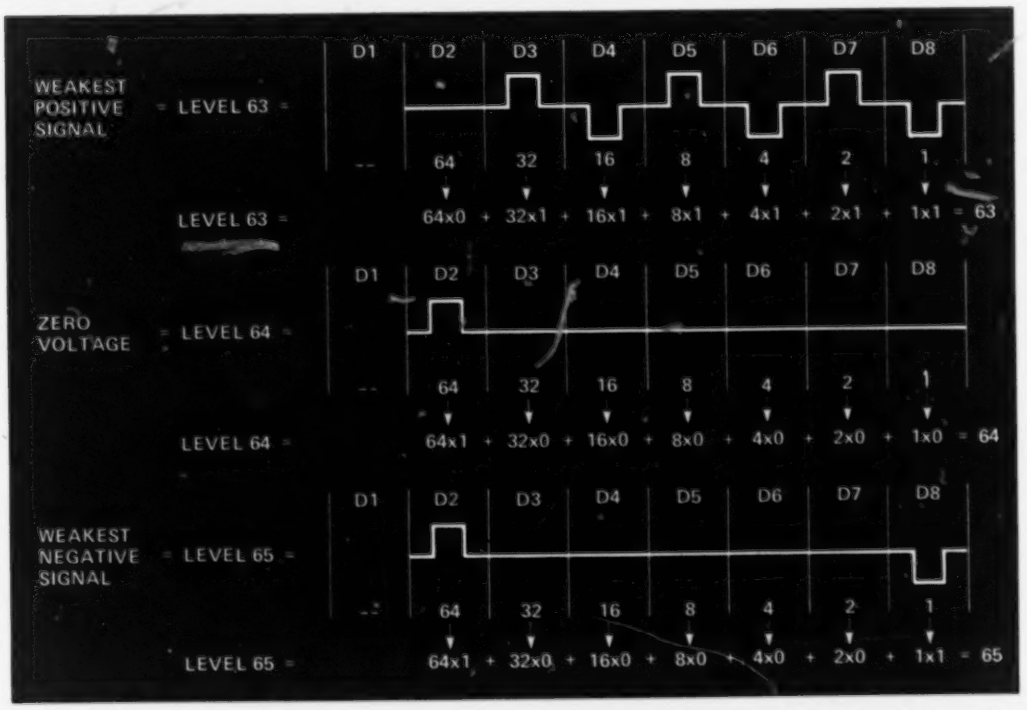
D1 D2 D3 D4 D5 D6 D7 D8
WEAKEST POSITIVE SIGNAL = LEVEL 63 =
64 32 16 8 4 2 1
LEVEL 63 = 64x0 + 32x1 + 16x1 + 8x1 + 4x1 + 2x1 + 1x1 = 63
D1 D2 D3 D4 D5 D6 D7 D8
ZERO VOLTAGE = LEVEL 64 =
64 32 16 8 4 2 1
LEVEL 64 = 64x1 + 32x0 + 16x0 + 8x0 + 4x0 + 2x0 + 1x0 = 64
D1 D2 D3 D4 D5 D6 D7 D8
WEAKEST NEGATIVE SIGNAL = LEVEL 65 =
64 32 16 8 4 2 1
LEVEL 65 = 64x1 + 32x0 + 16x0 + 8x0 + 4x0 + 2x0 + 1x1 = 65

Figure 1B. Resulting pulse patterns on the line and corresponding calculations for small voltage samples in a D1-type terminal. (Positive and negative pulses both represent a binary one.)

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dependent of signal level) which is the objective set for speech-loaded PCM telephone systems.

After the voltage is quantized (rounded off to the nearest quantization level), it is encoded into a 7-bit binary pulse pattern or binary word. A binary word consists of eight digits called D1 through D8. *The designation for the eight binary digits of the code word appear as D1 through D8 but should not be confused with the designation for D1- and D2- type terminals, they are two separate entities.* Digit D1 is used for signaling information only, while digits D2 through D8 represent the encoded version of the quantized sample (see Figure 1B). The 24 binary words representing the 24 voice channels plus the framing digit comprise one frame. There are 8000 frames per second and 8x24+1=193 bits per frame. Every other pulse is inverted to produce a bipolar pulse pattern for transmission.

In D2-type systems, the sampling rate is also 8000 times per second, but the number of quantization steps and the encoding method are different. In five frames out of every six all eight digits (D1 through D8) are used for encoding. There are then 255 discrete voltage levels available for quantization. These levels are numbered +0 to +127 and −0 to −127, zero quantization level corresponding to ±127. Figure 1C shows how a noise or low-level voice signal is sampled and quantized in a D2-type PCM system. Figure 1D shows examples of pulse patterns on the line. If the noise level in the terminal is sufficiently low to result in +127 or −127 quantized levels in every sample, a string of binary ones (pulses) broken by a zero (space) on the average only once every sixteen digits will be produced. In the sixth frame, one digit is used for signaling information so that only seven digits (127 levels) are available for quantizing. The availability of eight digits for quantization 5/6ths of the time provides for better signal quality than in a D1-type system.

Power Spectrum Curves

The power spectrum curve is an important tool in evaluating PCM-FDM crosstalk since from it can be derived the amount of potential interference to an FDM system channel which may be transmitted at a certain frequency.

The power spectrum (power as a function of frequency) of a D1/T1-type PCM bipolar pulse train as it would appear during traffic conditions at the output of a regenerator is shown in Figure 2. The curve is calibrated in dBm per 3.1-kHz slot. For this discussion, only a portion of Figure 2 is necessary since the maximum disturbance generated into an FDM line by a PCM system will occur at approximately 710 kHz and the FDM cable carrier systems of most concern for this discussion occupy the frequency range under 400 kHz. Figure 3 shows the significant portion of the power spectrum curve in expanded form. Also shown in expanded form, is the curve for a D2/T1-type system. Although the D1- and D2-type terminals cannot be operated end-to-end, they can both be operated over the T1-type repeatered line.

The power spectrum for a D1/T1-type system is based on a pulse density value of p=0.50, where p is the probability of a binary one (a pulse). This value for p is quite constant with varying loads in a D1/T1-type system provided that there is traffic on at least six of the 24 channels in the terminal. The p=0.50 implies that there is an equal probability of a one or a zero in the pulse train.

The curve for a D2/T1-type power spectrum is based on a pulse density of p=0.55 during busy-hour traffic condi-

tions. When loading decreases, p (pulse density) will increase, resulting in a decrease in P_b (power) at low frequencies (below approximately 420 kHz) and an increase around 710 kHz.

D1A and D1B Signaling

In the study of PCM to FDM interference, the type of signaling used in the PCM system will dictate the fundamental frequency or multiple thereof at which the greatest interference will occur when the PCM system is in the idle condition (no traffic).

Two types of signaling are used with D1-type terminals. These two signaling configurations bear the Western Electric designation of D1A and D1B.

When using D1A (also called "D1/D8") signaling the D1 digit in every binary word is used once in every frame to convey the signaling information. In the on-hook condition there is, then, always a pulse (a binary one) in the D1 time slot in every frame for a given channel. A problem arises when for certain signaling requirements (foreign exchange or revertive pulse signaling, for example) a second signaling channel is required. If this happens during voice transmission

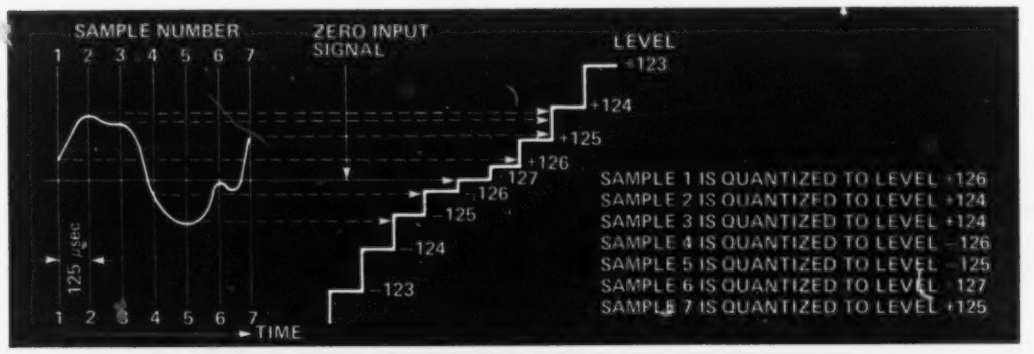

Figure 1C. In a D2-type terminal, each voltage is quantized to one of 255 possible levels.

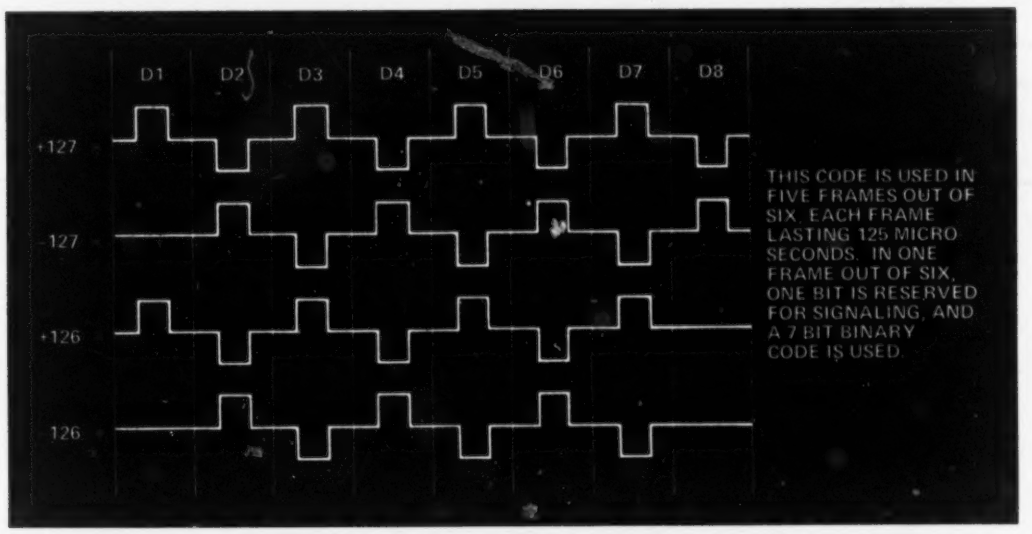

Figure 1D. Pulse patterns resulting from small voltage samples in a D2-type terminal will result in a pulse density close to 100 percent.

(this can happen, for example, when there is no answer supervision), only digits D2 through D7 (six digits) are available for representing the quantized sample. Six-digit encoding corresponds to 63 levels as compared to the usual 127 levels for seven-bit encoding. This six-digit encoding results in larger steps between levels and consequently in greatly increased quantizing noise within the PCM system itself.

To avoid any increase in noise due to requirements for more than one signaling channel, the D1B (also called "D1 only") signaling arrangement was developed. With D1B signaling, the signaling rate is divided by a factor of four so that the D1 digit is used for signaling information only once every fourth frame (per signaling channel). This effectively creates the potential

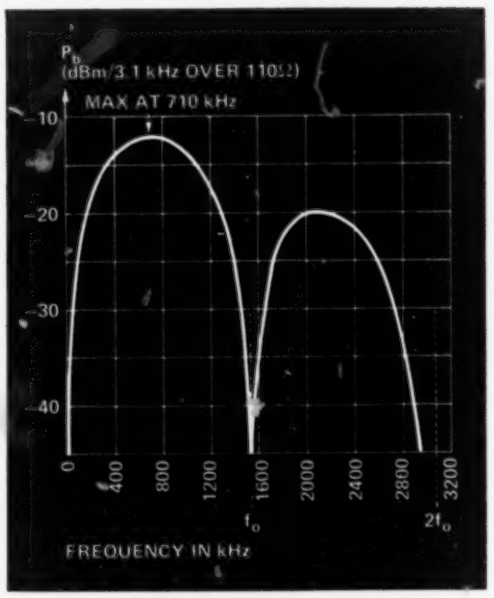

Figure 2. Power spectrum of a D1/T1 type system at the output of a regenerator during traffic conditions.

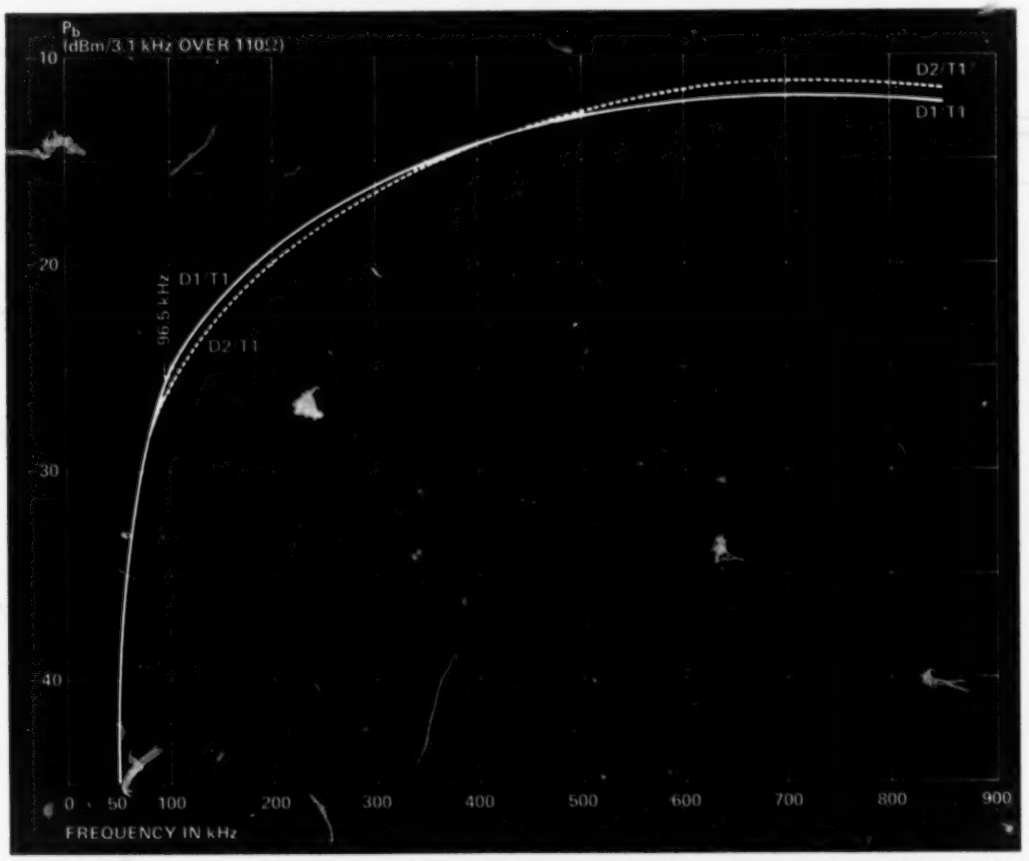

Figure 3. Expanded power spectrum curve of a T1-type pulse train under traffic conditions.

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for four signaling channels instead of one, although as a rule, not more than two channels are used. (See the March, 1971, issue of the GTE Lenkurt Demodulator for an extensive treatment of PCM signaling.)

Cable Characteristics

Aside from removing the dc component from the line, conversion of the PCM pulse train to a bipolar format also shifts the power spectrum to lower frequencies. This shift in power spectrum is advantageous for PCM systems because the crosstalk characteristics of cables are better at lower frequencies. Operation at lower frequencies also results in relaxed requirements on cable makeup, pair selection, and/or repeater spacing.

While the impedance of a cable pair is mainly a function of frequency, it also depends on such factors as cable gauge, insulation, and capacitance. Cable impedance falls rapidly from a value of 600-900 ohms at voice frequencies to approximately 100 ohms at 300 kHz and stays relatively constant above that frequency. A compromise value of 110 ohms has been chosen for the 50-400 kHz region which is the band of greatest interest for this study. This compromise impedance is accurate within this frequency range to within approximately 10 percent.

Idle/On-Hook Pulse Pattern

The idle/on-hook pulse pattern is important in the study of interference since an idle and quiet PCM system (all 24 channels idle) can sometimes (if the noise level is sufficiently low) produce a repetitive pulse pattern (resulting in a power spectrum confined to discrete frequencies only) instead of the random distribution of binary ones and zeros normally present when computing the power spectrum. This can cause excessive interference at certain discrete frequencies. A repetitious pulse pattern will appear on digits D2 through D8 in a D1-type system if a very low noise level is present at the terminal. *The value of the D1 digit in the idle condition is determined for the D1-type terminal only by the on-hook or off-hook condition of the channels.*

D1A Idle/On-Hook

If a D1-type system is arranged for D1A signaling, and a condition exists in which all channels are on-hook, with a very low noise level in the PCM terminal, there will be pulses for all D1 and D2 digits in every frame (digits D3 through D8 being zeros or spaces) since this sequence for digits D2 through D8 represents a zero input level (level 64) and since D1 is used strictly for signaling information (the on-hook condition is represented by a binary one). Such a repetitive pulse pattern has a line power spectrum (power concentrated at discrete frequencies). This means that the power in the signal can be represented by components of power at discrete frequencies which are multiples (harmonics) of a fundamental frequency, in this case, 193 kHz. This component may create serious interference in the 36-268 kHz band occupied by an N-type FDM carrier system, for example.

The fundamental frequency is derived for a periodic pulse pattern by the formula:

$$f_o = \frac{1}{T} = \frac{1}{5.18 \times 10^{-6}} = 193 \text{ kHz},$$

where T is the length of one period in seconds.

The periodic idle/on-hook pulse pattern and its corresponding line power spectrum for D1A signaling appear as shown in Figures 4A and 4B. A PCM terminal in a telephone office generally picks up some noise from

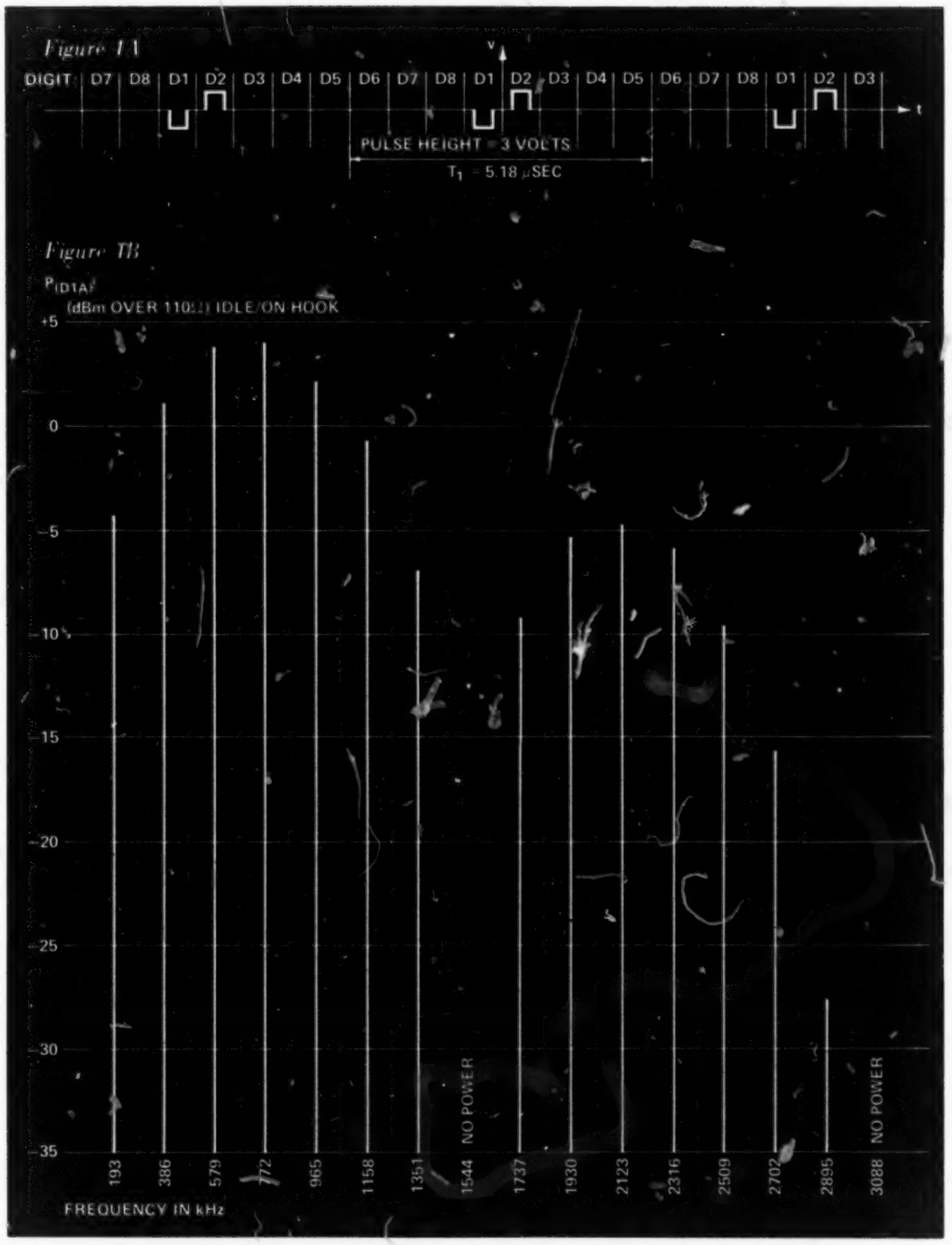

Figure 4A shows the pulse pattern as it appears out of a PCM terminal or regenerator in the idle/on-hook condition when D1A (D1/D8) signaling is used. The resulting line power spectrum is shown in Figure 4B.

Figure 4C represents the pulse pattern in three frames out of four for the idle/on hook condition and D1B signaling.

Figure 4D is the line power spectrum resulting from the idle/on-hook pulse pattern in a D1-type terminal when D1B (D1 only) signaling is used. That pattern is according to Figure 4A every fourth frame; according to Figure 4C the remaining three (out of four) frames.

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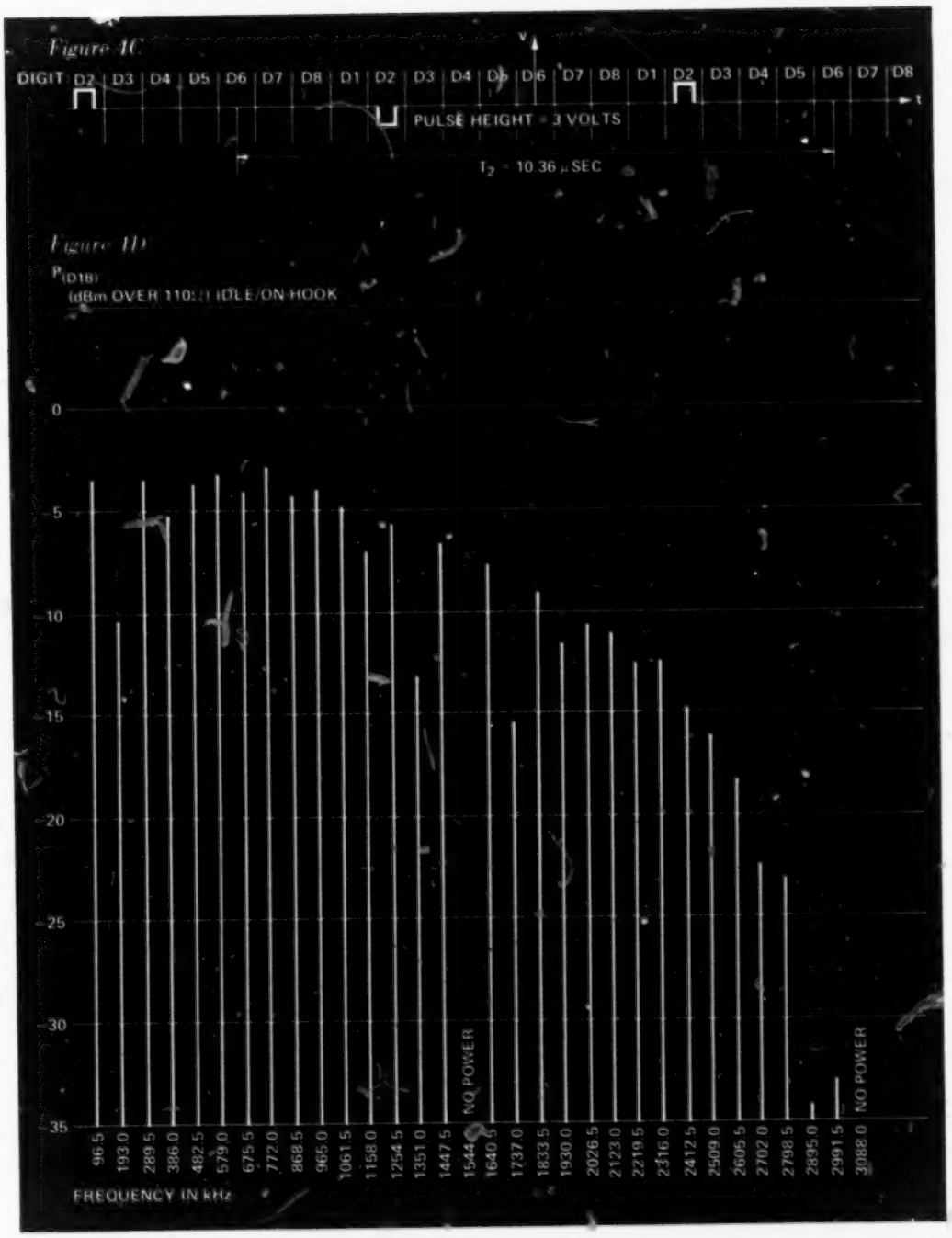


switching transients, which causes the power spectrum on the transmission line to be less clean-cut than that shown in Figure 4B. In most working systems, noise will cause the quantized samples of the input signal to fluctuate randomly around level 64. These random fluctuations will introduce more pulses per binary word and thus more high-frequency components to the line. Even rather small noise levels (for example, resulting in levels 63 or 65 most of the time, rather than 64) will result in a pulse density of approximately 50 percent. *Only when all voltage samples are consistently quantized to zero level does the power spectrum become a series of spectral lines.*

Figure 5. Power spectrum for a working PCM system during a busy-hour condition (10 a.m.) on a week day.

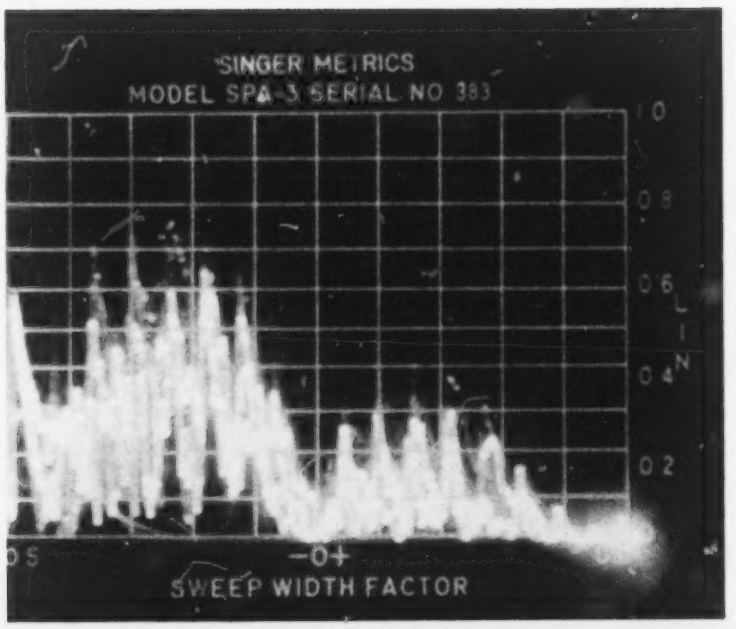
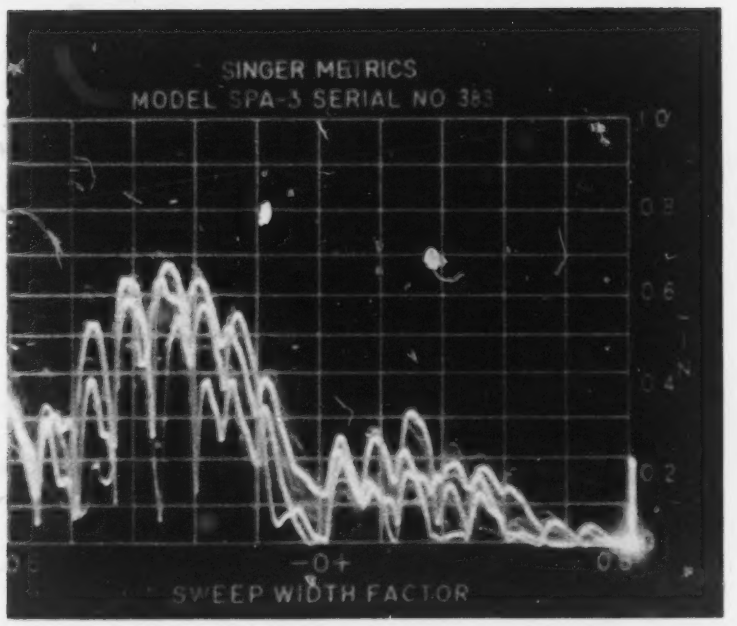


Figure 6. Power spectrum for a working PCM system during a low traffic condition (midnight).



Figures 5 and 6 show the power spectrum of the line signal as it appears at the output of a PCM terminal under different traffic conditions. These photographs were taken in the field on a working 24-channel D1A system. Figure 6 shows that the power spectrum only *approaches* a spectral line condition due to the presence of ambient noise. However, a spectral line condition can be attained in the laboratory where ambient noise is more strictly controlled.

Although a periodic pulse pattern is a rather unusual case since it corresponds to all channels off hook and a very low noise level, it is important because it usually represents the worst

interference condition as far as FDM channels in the corresponding discrete frequency slots are concerned. As the pulses occur randomly with traffic, the power spectrum of a PCM system will tend to assume a smooth curvature as shown in Figure 3. Figure 4B represents the worst case for the all channels on-hook condition, as far as crosstalk at low frequencies is concerned.

D1B Idle/On-Hook

When a terminal is arranged for D1B ("D1 only") signaling, the idle/on-hook pulse pattern is somewhat more complicated than for D1A signaling. In one frame out of four the pulse pattern will be as shown in Figure 4A; in three frames out of four it will be as shown in figure 4C. The pulse train in one frame out of four for the idle/on-hook condition is thus identical to that for D1A signaling. This will produce lines in the power spectrum at multiples of 193 kHz as for D1A signaling, but their magnitudes are reduced by a factor of four (6dB) because it represents only the pulse pattern in every fourth frame. The important thing to be noted about the power spectrum for an all channels idle and on-hook condition, (as in Figure 4D) is that it consists of two sets of spectral lines for D1B signaling. One set has lines at all odd multiples of 96.5 kHz caused by the pulse pattern in three out of four frames. The other set has lines at even multiples of 96.5 kHz (which is the same as multiples of 193 kHz) caused by the pulse pattern in one out of every four frames.

D2/T1-Type Idle/On-Hook

The pulse pattern for the idle/on-hook conditions for a D2/T1-type system is a sequence of consecutive pulses (a string of binary ones), broken by an occasional space. If the system is idle with all channels in the on-hook condition, and the noise level is sufficiently low, the voltage samples will all be quantized to +127 or −127 in five frames out of six; to +63 or −63 in one frame out of six. The signaling digit for the on-hook condition is a binary one. For this condition, on the average 15 out of every 16 digits will be binary ones. Analysis of this type of pulse train shows a reduction of single-tone interference below 400 kHz amounting to 11 dB (compared to idle/on-hook D1A) or 7 dB (compared to idle/on-hook D1B).

Crosstalk Evaluation

From a study of idle/on-hook conditions for D1A and D1B signaling it is apparent that PCM to FDM interference will show greatest potential for disturbance at multiples of 96.5 kHz or 193 kHz during the times of the day or night when most of the PCM channels are idle. The value of the worst case component under this condition can be obtained from the applicable diagram in Figure 4. It is possible that this disturbing effect from the PCM system in its idle condition will in some cases necessitate the elimination of FDM channels in baseband slots at or adjacent to multiples of 96.5 kHz.

In Part III of PCM-FDM COMPATIBILITY, the theoretical aspects of compatibility which have been discussed in the previous two issues of the Demodulator will be put to practical application. A hypothetical PCM-FDM combination will be evaluated to determine if the two systems are compatible.

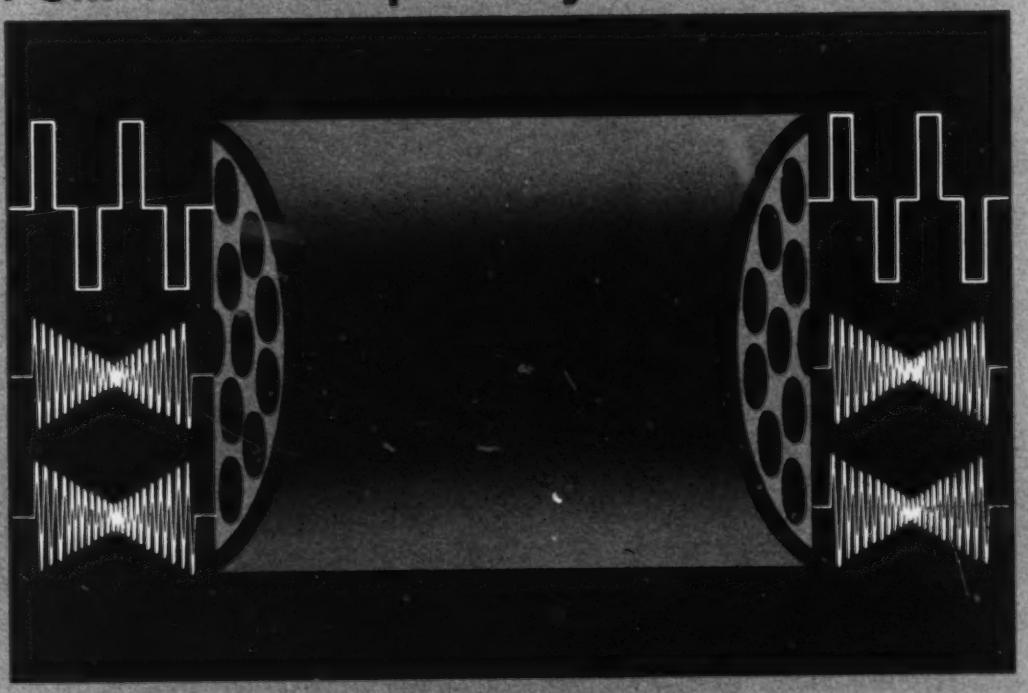
GTE LENKURT

DEMODULATOR

SEPTEMBER 1971

PCM-FDM Compatibility

Part 3



Subjection of an FDM system to interference from PCM signals is the major factor which discourages the user of communications equipment from placing PCM and FDM systems in the same cable sheath. By giving careful consideration to direction coordination of cable, and by evaluating the effects of PCM to FDM crosstalk, single-tone interference, and length of repeater sections, the user may find his FDM system compatible with PCM without extensive modifications.

Parts I and II of the PCM-FDM compatibility series dealt with the empirical and theoretical aspects of PCM and FDM systems which lie in the same cable sheath. Some of the factors influencing the amount of interference between these two types of systems are crosstalk coupling loss, length of exposure of FDM to PCM, the frequency band occupied by the FDM system, and the type of PCM signaling utilized. The discussion of these subjects brings to light a way of evaluating the amount of interference which the FDM system receives from the PCM system.

A series of steps may be taken to evaluate the possibility of compatibility between PCM and FDM systems which operate on pairs within the same cable sheath. To demonstrate how this series of steps can be useful to the communications equipment user, an example is given in this issue (using a hypothetical PCM-FDM combination) on the process of estimating the minimum crosstalk coupling loss required if two systems are to be compatible.

The example for crosstalk evaluation will employ a GTE Lenkurt 24-channel 91A PCM system (D1/T1-type) equipped for D1A signaling and a GTE Lenkurt 47A (an N-type FDM system) equipped with compandors. The calculations are valid for any D1/T1-type PCM system and any N1 or N2-type FDM system.

The 47A is a 12-channel, double-sideband, amplitude-modulated carrier system which operates over two cable pairs, one for each direction of transmission. It is end-to-end compatible with Western Electric N1 or N2 systems (depending on the option of 47A used). Compandors are optional for these systems. On any section of the cable, the two directions of transmission utilize different frequency line groups. The low-frequency group extends from 40 to 128 kHz and the high-frequency group from 176 to 264 kHz as shown in Figure 1. In each repeater there is a modulator which shifts the signal from one band to the other (frequency frogging) in order to combat near-end crosstalk.

For this example it is assumed that maximum-length repeater section lengths are used for the 47A system (40 dB at 176 kHz) and that end sections (or any sections adjacent to a telephone switching office) do not exceed 25 dB at 176 kHz. The 40-dB value is the maximum allowable power loss over an intermediate repeater section where little interference will be encountered from external sources; for this discussion an intermediate repeater location not at a switching center will be referred to as a "low-noise point." The 25-dB value is the maximum allowable power loss over a repeater section adjacent to an office (an end section, for example). At an office the repeater is subject to interference from office switching equipment; for this discussion offices will be referred to as "high noise points." For 22-gauge PIC (polyethylene insulated

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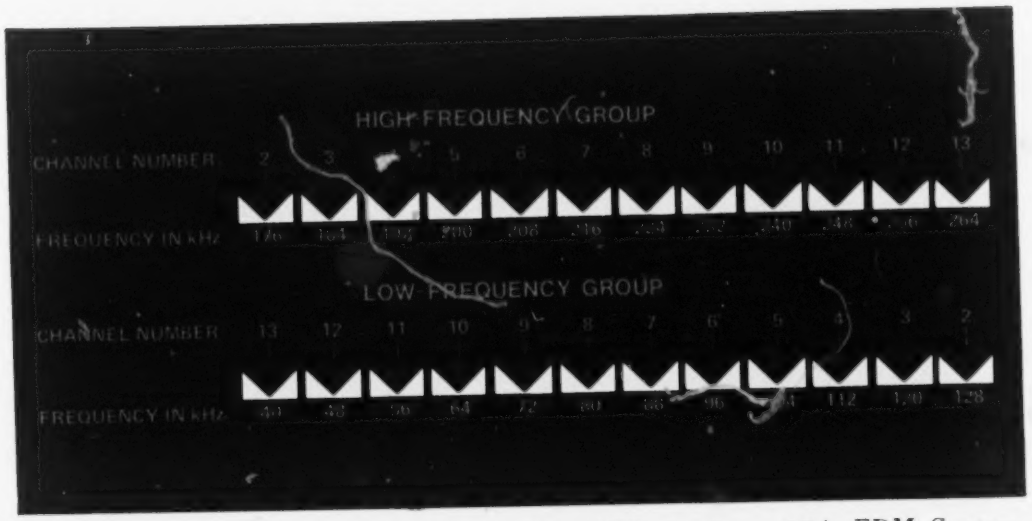

Figure 1. Frequency designations for the GTE Lenkurt 47A FDM System. Channel 1 (not shown) is an optional channel which is seldom used due to performance limitations at that frequency although it may be used in lieu of any of the other available channels.

cable) with a capacitance of 0.083 μF per mile, the 40- and 25-dB values correspond to repeater section lengths of 3.88 miles and 2.42 miles, respectively. The loss at 772 kHz (the loss at this frequency determines the PCM repeater spacing) is 90 dB over a 3.88-mile section of such cable. Assuming that the PCM intermediate repeater sections are exactly one third of the 47A repeater section (this corresponds to 30 dB at 772 kHz), that the 47A repeater locations within the section exposed to PCM interference always coincide with a PCM repeater point, and that the exposure to PCM occurs over three 47A intermediate repeater sections plus one end section, the system layout will appear as in Figure 2.

Noise Interference

The interference from a PCM system consists either of noise or single-tone interference depending on the traffic loading of the PCM system and the noise level at each PCM terminal. The first consideration will be that of noise interference from a traffic-loaded PCM system.

The near-end crosstalk interference from a PCM system to an FDM system is shown in Figure 2 by the green arrows which indicate the near-end crosstalk paths of importance. The interference from PCM is most severe at the high-level outputs of the PCM repeaters (regenerators). However, the only near-end crosstalk of importance occurs on the PCM repeater sections adjacent to FDM repeater receive-inputs, as the green arrows in Figure 2 indicate. This is because the level of the received signal on the FDM system is the lowest and most noise-sensitive at that point. The PCM to FDM near-end crosstalk originating on PCM repeater sections not adjacent to an FDM repeater receive-input will be attenuated by 10 dB or more before reaching the FDM repeater input and can be neglected.

The allowable degradation of noise performance in the 47A system has been chosen such that the presence of PCM carrier interference should not cause the noise performance to deteriorate to worse than 27 dBrnc. This is one dB worse than the worst line-up

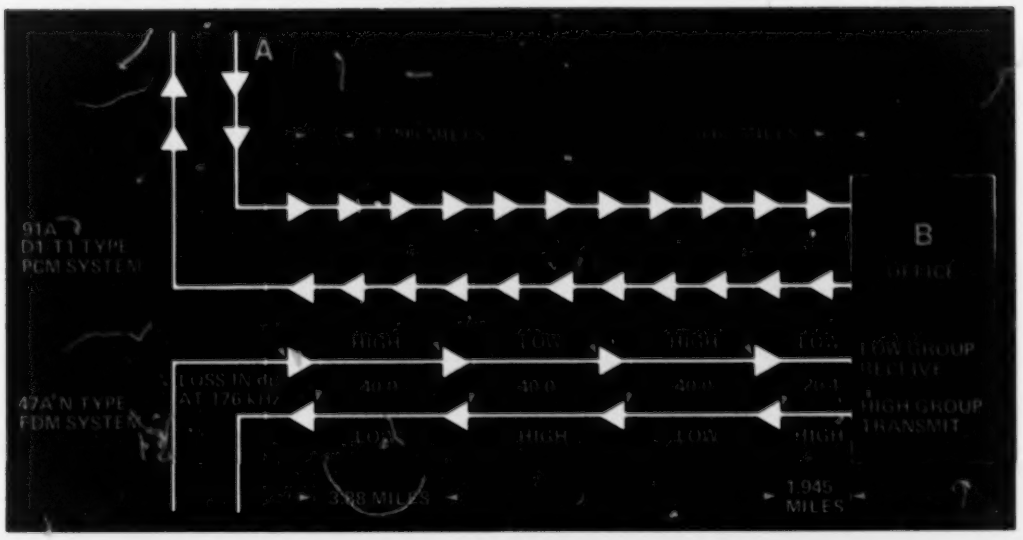

Figure 2. PCM-FDM combination showing three intermediate repeater sections and one end section of the FDM system exposed to PCM interference.

noise performance allowed for a long distance 47A system without PCM interference (26 dBrnc). Based on this requirement, the total noise contribution originating from PCM carrier systems must not exceed 20 dBrnc, since by dB addition laws, 26 dBrnc + 20 dBrnc = 27 dBrnc. The dBrnc unit is used to measure absolute noise and from the conversion table shown in Figure 3, a 20-dBrnc value converts to 100 pW psophometrically weighted (100 pWp).

A performance requirement of 20 dBrnc for PCM interference corresponds to an FDM signal-to-PCM interference noise ratio (test tone-to-PCM interference noise ratio) of 68 dB (as shown in Figure 3). The expression "signal-to-noise ratio" generally used in FDM system terminology actually means test tone-to-noise ratio since it refers to a test tone which is injected into the system from a signal generator for measurement purposes. At test tone level, a 47A non-compressed carrier is amplitude-modulated with a modulation index of 0.35 (35 percent). This 35% value was chosen in the initial system design to avoid exceeding 100 percent modulation at even the highest speech volumes.

Figure 4 shows the relationship between carrier and test tone signals in one channel of an FDM system. In order to solve for unknown noise levels a meaningful relationship must be established between the carrier-to-noise and signal-to-noise ratios. For this non-compressed, double-sideband, amplitude-modulated, 47A FDM system, in which a test tone modulates the carrier 35 percent, the following equation is true:

Equation 1

$$\left(\frac{C}{N}\right)_{6.2\ \text{kHz}} = \left(\frac{S}{N}\right)_{3.1\ \text{kHz}} + 9\ \text{dB}$$

where C/N stands for FDM carrier-to-PCM interference noise ratio (where the carrier is at one specific frequency and the PCM noise is over 6.2 kHz) and S/N for FDM test tone-to-PCM interference noise ratio, with reference to the voice frequency drop point. The 3.1-kHz value, corresponds to the usable sideband bandwidths in a voice channel. Since the 47A uses double

dBrnc	pWp	S/N (dB)
6	4.0	82
7	5.0	81
8	6.3	80
9	8.0	79
10	10.0	78
11	12.6	77
12	15.9	76
13	20.0	75
14	25.1	74
15	31.6	73
16	39.8	72
17	50.0	71
18	63.0	70
19	79.5	69
20	100.0	68
21	126.0	67
22	159.0	66
23	200.0	65
24	251.0	64
25	316.0	63
26	398.0	62
27	500.0	61
28	630.0	60
29	795.0	59
30	1000.0	58
31	1260.0	57

All units are given with reference to test tone level of zero dBm.
dBrnc — C-message weighted
pWp — Picowatts psophometrically weighted.

Figure 3. Noise measurement conversion table.

sideband operation, each carrier is associated with noise interference over a bandwidth of 6.2 kHz. Equation 1 states that carrier-to-noise is equal to the signal-to-noise + 9 dB.

The maximum allowable noise performance for a GTE Lenkurt 47A system is 26 dBrnc. In a case where the repeater sections are of acceptable lengths and good cable and line-up procedures are used, the noise performance will usually be much better than 26 dBrnc. However, this discussion will proceed as if the noise performance on the system was at the 26-dBrnc point (worst case) before the addition of PCM interference. In order to allow for this PCM interference, one additional dB of interference will be accepted which will make the total noise performance 27 dBrnc. For this discussion the 20-dBrnc value will be regarded as the total noise interference to the FDM system although it must be remembered that a 26-dBrnc noise value *does* exist in addition to the 20 dBrnc.

The 20-dBrnc PCM noise requirement previously calculated corre-

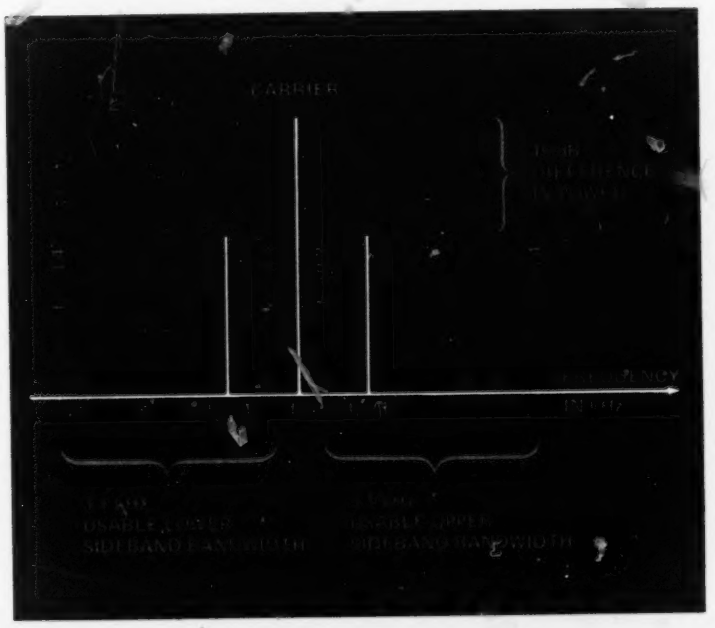

Figure 4. When a carrier of frequency f_c is modulated by a sinusodial 1-kHz test tone, sideband frequencies appear at frequencies (f_c–1) kHz and (f_c+1) kHz. Each one of these two sideband frequency components are of a power level 15 dB below the level of the carrier. This is based on the test tone modulating the carrier with a modulation index of 0.35 (such as in a non-compandored 47A system).

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sponds to an FDM signal-to-PCM interference noise ratio of 68 dB, and thus converts to a requirement for FDM carrier-to-PCM interference noise ratio of:

$$\left(\frac{C}{N}\right)_{6.2\text{ kHz}} = \left(\frac{S}{N}\right)_{3.1\text{ kHz}} + 9\text{ dB}$$

$$\left(\frac{C}{N}\right)_{6.2\text{ kHz}} = 68 + 9\text{ dB}$$

$$\left(\frac{C}{N}\right)_{6.2\text{ kHz}} = 77\text{ dB; (non-compressed).}$$

For this discussion a compandor will be inserted in accordance with the original conditions at the beginning of this example. This produces a 20-dB compandor advantage and results in a requirement of:

$$\left(\frac{C}{N}\right)_{6.2\text{ kHz}} = 57\text{ dB (compressed).}$$

The carrier with the lowest power level will differ in level and frequency depending upon the 47A repeater section length and whether the low-group or the high-group is being observed. Levels will thus be different on repeater sections adjacent to switching centers (as in end sections) compared to intermediate sections adjacent to low-noise points. If the spacing rules for N-type carrier are adhered to (end-sections not to exceed 25 dB at 176 kHz, intermediate sections not exceeding 40 dB), the lowest carrier levels on a 47A system have been calculated to be approximately:

(a) At a high-group repeater input at the high-frequency end of the band (264 kHz) . . . −48 dBm

(b) At a low-group repeater input at the high-frequency end of the band (128 kHz) . . . −42 dBm

(c) At a high- or low-group repeater input or terminal input located in or adjacent to a switching center . . . . . −28 dBm.

These "lowest" FDM carrier power levels are significant when evaluating PCM to FDM interference since it is at these levels that an interfering PCM system will have the greatest effect on FDM. It is assumed throughout the following calculations that the spacing rules quoted above were followed when laying out the N-type carrier system.

A repeater input on a section adjacent to a switching center is at least 14 dB less sensitive to PCM interference than other intermediate sections due to its shorter length (compare values −28 dBm versus −42 dBm and −28 dBm versus −48 dBm). End-sections and other sections adjacent to high-noise points can thus be neglected for the purpose of these interference calculations if there are at least as many normal (adjacent to low-noise points) intermediate 47A repeater sections in the section being exposed to PCM interference as there are 47A repeater sections adjacent to high-noise points. The approximation error thus incurred is no more than 0.2 dB.

If a 47A carrier system is exposed to PCM interference over several intermediate sections (as in tnis example), about half the number of sections exposed (for any direction of transmission) are high-group sections and half are low-group sections. Consideration must therefore be given to the relative effects of interference into these two groups.

High-Group Repeater Input

The minimum FDM carrier-to-PCM noise ratio requirement has been calculated to be 57 dB (68 dB + 9 dB − 20 dB = 57 dB). The lowest power level (this is the worst acceptable case con-

dition) of the highest-frequency carrier (at 264 kHz) is −48 dBm as previously mentioned. The maximum allowable noise level due to PCM carrier interference in the 47A FDM system is then calculated as follows:

$$\left(\frac{C}{N_{max}}\right)_{6.2\ kHz} = 57\ dB.$$

By virtue of the fact that C is −48 dBm in the worst case, and that the dB division rules state that division of two values effectively means subtraction of these values when expressed in dB form, it follows that,

$$-48\ dBm - \left(N_{max}\right)_{6.2\ kHz} = 57\ dB$$

$$\left(N_{max}\right)_{6.2\ kHz} = -48\ dB - 57\ dB$$

$$= -105\ dBm$$

or

$$\left(N_{max}\right)_{3.1\ kHz} = -108\ dBm$$

where N_{max} is the maximum allowable noise level in the 6.2-kHz or 3.1-kHz slots at 264 kHz. Dividing the bandwidth by 2 makes the requirement more severe by 3 dB and hence, N_{max} in a 3.1 kHz slot becomes −108 dBm.

The noise power in a 3.1 kHz slot centered at 264 kHz of the PCM system is −17 dBm according to the power spectrum curve of Figure 5. The difference between −17 dBm and −108 dBm is 91 dB. This would be the requirement for near-end crosstalk coupling loss at 264 kHz between PCM and FDM cable pairs in this example if the following were true:

(a) The effect of far-end PCM to FDM crosstalk could be neglected

(b) Only one PCM system interfered with the FDM system

(c) Only one 47A repeater section were exposed to PCM interference.

Also, the effects of single-tone interference have been neglected up to this point but will be covered in following paragraphs along with the effects of a PCM system interfering with more than one FDM repeater section.

Low-Group Repeater Input

The lowest power level of the highest-frequency carrier (at 128 kHz) as previously stated is −42 dBm. A carrier-to-PCM noise requirement of 57 dBm thus corresponds to a maximum allowable noise level, due to PCM interference, of:

$$\left(N_{max}\right)_{6.2\ kHz} = -42\ dBm - 57\ dB$$

$$= -99\ dBm.$$

This value is derived from the subtraction of the carrier-to-noise level (57 dB) from the lowest carrier level (−42 dBm).

or

$$\left(N_{max}\right)_{3.1\ kHz} = -102\ dBm$$

where N_{max} is the lowest allowable noise level in the 6.2-kHz or 3.1-kHz slots at 128 kHz. Dividing the bandwidth by 2 makes the requirement more severe by 3 dB and hence it becomes −102 dBm.

The maximum allowable level of PCM interference is thus 6 dB (108 dB − 102 dB = 6 dB) greater (less severe) at a low-group intermediate repeater input than at an input using the high frequency line-group. Also, the noise power in a 3.1-kHz slot centered at 128 kHz (the highest carrier frequency in the low group) of the interfering PCM signal is 6 dB lower than in such a slot centered at 264 kHz (−23 dBm compared to −17 dBm as shown in

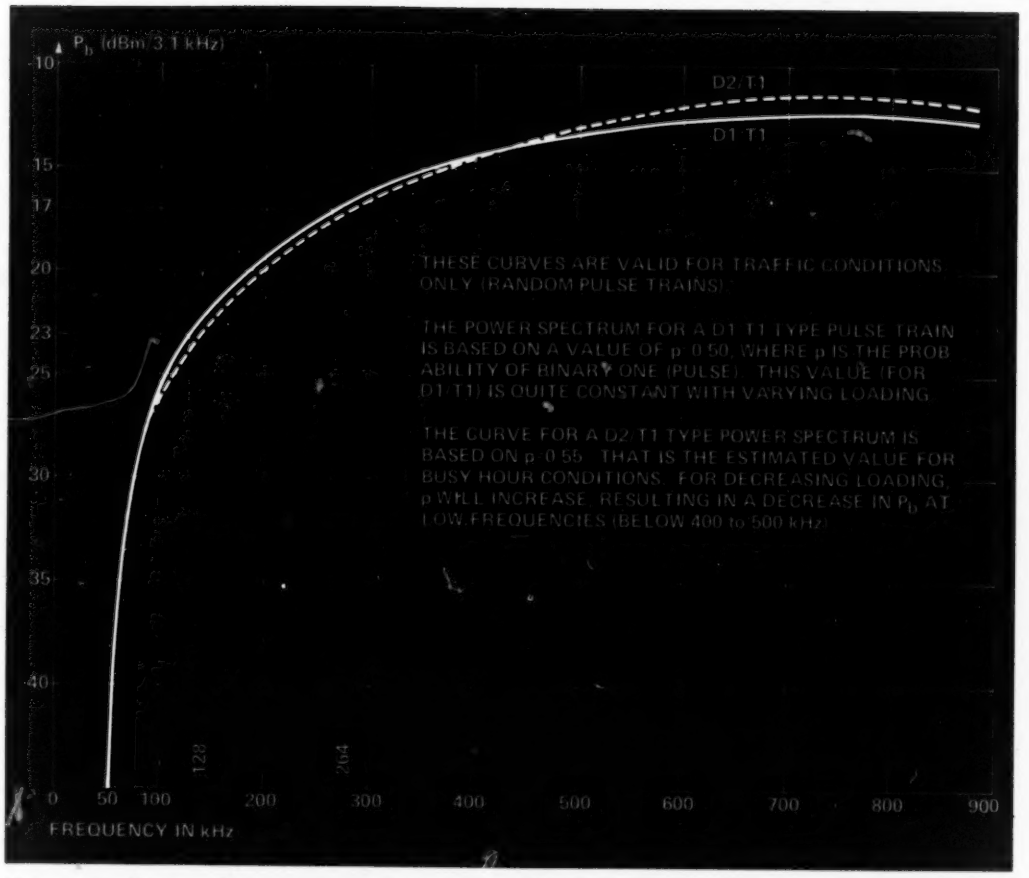

P_b (dBm/3.1 kHz)
-10
-15
-17
-20
-23
-25
-30
-35
-40
D2 T1
D1 T1
THESE CURVES ARE VALID FOR TRAFFIC CONDITIONS ONLY (RANDOM PULSE TRAINS).
THE POWER SPECTRUM FOR A D1 T1 TYPE PULSE TRAIN IS BASED ON A VALUE OF p 0.50, WHERE p IS THE PROBABILITY OF BINARY ONE (PULSE). THIS VALUE (FOR D1 T1) IS QUITE CONSTANT WITH VARYING LOADING.
THE CURVE FOR A D2 T1 TYPE POWER SPECTRUM IS BASED ON p 0.55. THAT IS THE ESTIMATED VALUE FOR BUSY HOUR CONDITIONS. FOR DECREASING LOADING, p WILL INCREASE, RESULTING IN A DECREASE IN P_b AT LOW FREQUENCIES (BELOW 400 to 500 kHz).
128
264
0
50
100
200
300
400
500
600
700
800
900
FREQUENCY IN kHz

Figure 5. Power Spectrum of a T1-type PCM pulse train under traffic conditions at the output of a regenerator.

Figure 5). A low-group intermediate repeater input is thus 12 dB less sensitive to interference from a PCM system with traffic than such an input using the high line-group (due to two 6-dB advantage factors).

Based on the above calculations, it can be concluded that only the high-group intermediate repeater inputs, being the ones most sensitive to interference, are going to determine the required value of near-end or far-end crosstalk coupling loss between PCM and FDM cable pairs. Therefore, in this example the effects of all low-group repeater inputs may be neglected. The error incurred by this approximation does not exceed 0.5 dB provided that the section of the 47A system exposed to PCM interference contains more than one intermediate 47A repeater section.

PCM Noise Conclusion

For this example, in the A to B direction of transmission shown in Figure 2, two high-group intermediate repeater sections are exposed to PCM interference. Had only one such section been exposed, the near-end crosstalk coupling loss requirement would have been 91 dB at 264 kHz. Since there are two exposed high-group intermediate FDM repeater sections, the requirement is 91 + 10 log 2 dB, or 94 dB, for near-end crosstalk coupling loss at 264 kHz. This is based on one interfering PCM system and the length of its exposure to the FDM system as shown in Figure 2.

The value of 94 dB for near-end-crosstalk coupling loss is based on total PCM to FDM noise crosstalk contributions. The assumption is made here that near-end crosstalk contributions will be much more likely to cause interference than the contributions of PCM to FDM interference due to far-end crosstalk. If this assumption cannot be made, half of the crosstalk contribution can be assigned to near-end crosstalk (making that requirement 3 dB more severe, or 97 dB), and half to far-end crosstalk. The requirements for coupling losses between PCM and FDM cable pairs are then as follows:

(a) Near-end crosstalk coupling loss requirement at 264 kHz is 97 dB

(b) Far-end crosstalk coupling loss requirement at 264 kHz (as measured over one PCM repeater section length) is (97 – C dB), where C is the loss in dB at 264 kHz of the cable pair over one PCM repeater section length.

In the B to A direction of transmission shown in Figure 2, there is only one intermediate high-group repeater section exposed to PCM interference that is not adjacent to a high-noise point. For simplicity, this example has considered only the worst direction of transmission (the A to B direction).

Single-Tone Interference

The next problem to consider is that of single-tone near-end interference (between opposite directions of transmission) from the PCM system into the 47A FDM system. Figure 6 shows that the only frequency of concern in this case is 193 kHz (D1A-type signaling, and highest frequency in the FDM system of 264 kHz).

An interfering tone at 193 kHz will fall at the 1-kHz point (1 kHz on one side of the carrier) in the upper sideband of Channel 4 of the high group of the 47A system (see Channel 4, Figure 1). The maximum allowable level of such a 1-kHz tone is set to −70 dBm0, that is, 70 dB below test tone level. This is consistent with previous assumptions since this corresponds to 100 pWp at the zero-level test-tone point. The maximum allowable PCM noise level in the previous calculations was 20 dBrnc, which corresponds to 100 pW psophometrically weighted (see Figure 3). It should be remembered that the PCM to FDM interference occurs *either* as noise *or* single-tone interference, never both types simultaneously.

In this case (D1A-type signaling) only the high-group repeater inputs are of interest, since the interfering tone falls within the high-group frequency range. End sections or repeater sections adjacent to high-noise points can be disregarded as before if the length of the 47A system section being exposed to PCM interference contains at least as many normal (adjacent to low-noise points) intermediate 47A repeater sections as there are 47A repeater sections adjacent to high-noise points.

The lowest carrier level encountered at a high-group repeater input is −48 dBm, in accordance with the value used earlier in this example. This value is for the highest-frequency carrier (Channel 13) at 264 kHz. For Channel 4, the lowest level encountered is −41 dBm. Since in a 47A system without compandors the level of each sideband of a test tone is 15 dB below the carrier level (see Figure 4), the lowest such sideband level encountered is −56 dBm (−41 dBm − 15 dB). The interfering tone must be at least 70 dB below that, in other words, less than −126 dBm.

For the 47A system in this discussion, the compandor advantage allows

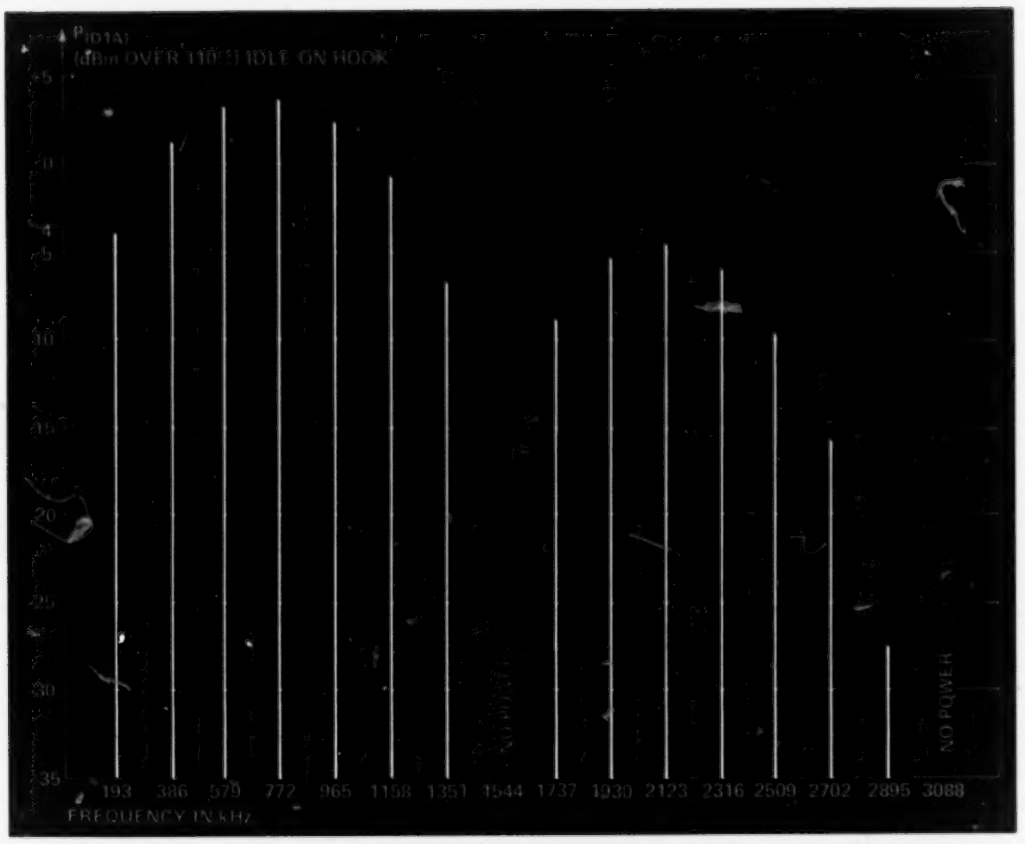


Figure 6. The line power spectrum which results in a D1-type terminal under idle/on-hook conditions when D1A (D1/D8) signaling is used.

this requirement to be relaxed by 20 dB to −106 dBm.

The level of the 193-kHz tone of an idle PCM system with D1A-type signaling is −4 dBm as shown in Figure 6. The difference between −4 dBm and −106 dBm is 102 dB. The requirement for near-end crosstalk coupling loss at 193 kHz between PCM and FDM cable pairs thus becomes 102 dB per exposed high-group 47A intermediate repeater section. Since there are two such sections exposed in the A to B direction of transmission as shown in Figure 2, this requirement becomes 105 dB (102 + 10 log 2 dB = 105 dB) for this direction. (The requirement for the other direction is 3 dB less, but for simplicity only the worst case will be considered here.) This 105-dB value is based *only* on single-tone interference and on the assumption that the following additional circumstances are true:

(a) the effect of far-end PCM to FDM crosstalk can be neglected

(b) only one PCM system is involved.

If far-end PCM to FDM crosstalk can for some reason not be neglected, 3 dB should be added to the requirement above. This new value (108 dB at 193 kHz) becomes the new near-end crosstalk requirement; (108-D) dB is the far-end crosstalk requirement as measured over one PCM repeater section length. (D is the loss in dB of the cable pair at 193 kHz over one repeater section length of the PCM system.) This assumption effectively assigns

half of the single-tone interference to near-end crosstalk and half to far-end crosstalk contributions.

Overall Conclusion For This Example

In this example, the resulting requirements on near-end and far-end crosstalk were:

(a) *For near-end crosstalk over one repeater section length of the PCM system,*
97 dB at 264 kHz
108 dB at 193 kHz

(b) *For far-end crosstalk over one repeater section length of the PCM system,*
(97-C) dB at 264 kHz
(108-D) dB at 193 kHz

where, C and D are the losses in dB of the cable pair at 264 and 193 kHz, respectively, over one PCM system repeater section length.

If the requirements at 264 kHz can be met (this is necessary to combat noise across the band coming from the PCM system when it is loaded with traffic) but the requirements at 193 kHz cannot be simultaneously met, consideration should be given to removing the 47A channel affected (Channel 4) from service.

Conclusions Regarding "T to N" PCM-FDM Interference

The results and conclusions of the example just discussed are valid for any D1/T1-type PCM system equipped for D1A-type signaling, disturbing an N1 or N2-type FDM system equipped with compandors.

If the D1/T1 system is equipped for D1B signaling there will be an additional component of single-tone interference falling at 96.5 kHz, corresponding to the 500-Hz point (on one side of the carrier) of one of the sidebands of Channel 6 in the lower line group. This will produce an additional requirement (at that frequency) for near-end and far-end crosstalk coupling loss, respectively.

If the PCM system is a D2/T1-type system, the single-tone interference problem is reduced significantly.

The calculations regarding noise interference from a traffic-loaded PCM system are the same for a D1B as for a D1A-type PCM system. For a D2/T1-type system, a separate curve is used (see Figure 5).

If a D1/T1- or D2/T1-type PCM system is disturbing an N3-type system such as the GTE Lenkurt 46B, there is a 3-dB disadvantage since the single-sideband 46B system does not have the advantage of coherent detection of a double-sideband signal (as the 47A does) since,

Equation 2

$$\left(\frac{P}{N}\right)_{6.2\ \text{kHz}} = \left(\frac{S}{N}\right)_{3.1\ \text{kHz}} + 12\ \text{dB}$$

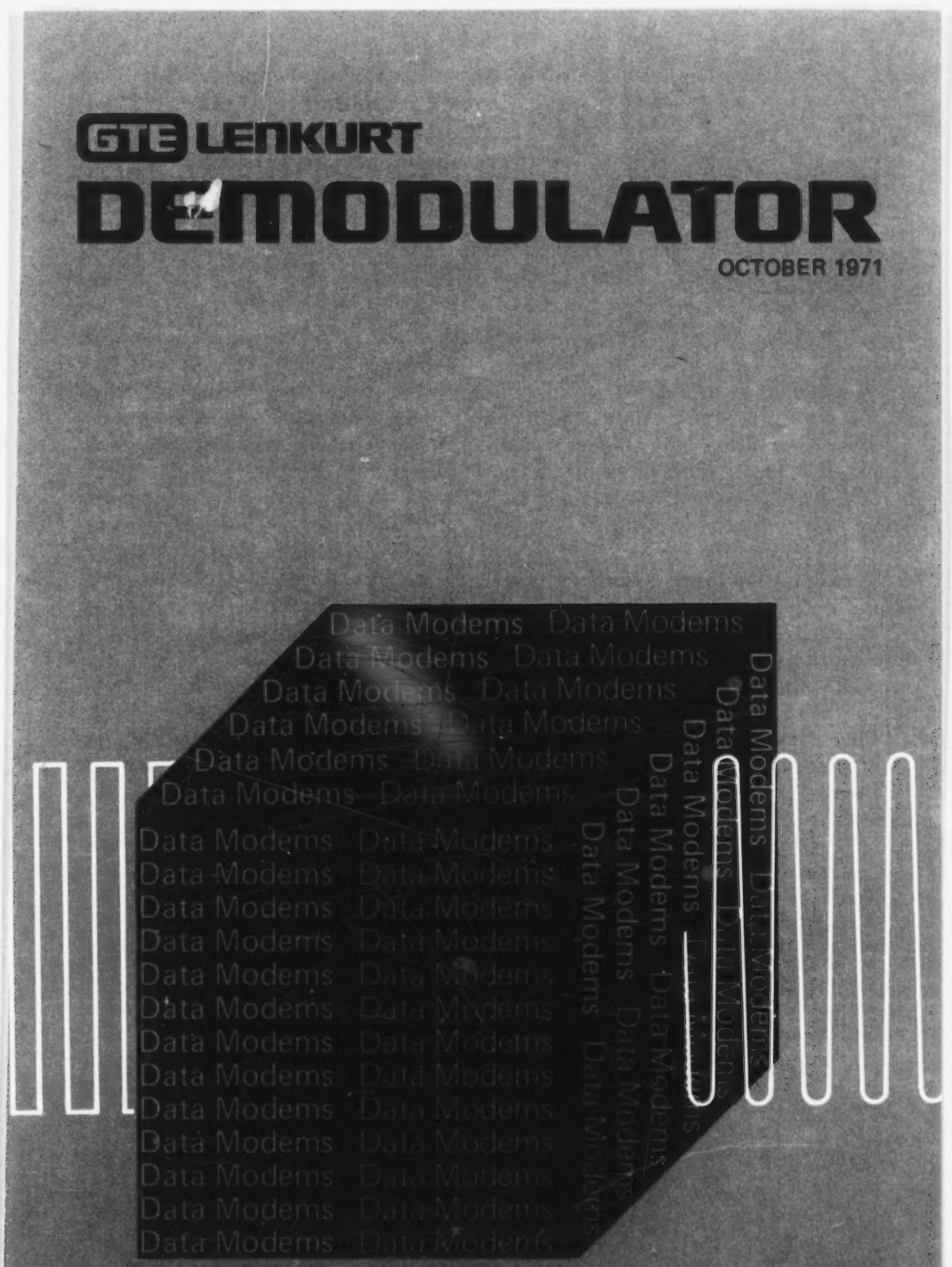
where P/N is the pilot-to-PCM interference noise ratio, and S/N is the test tone-to-PCM interference noise ratio. In equation 2, the 3-dB disadvantage shows up in the +12-dB value when compared to the +9-dB value of Equation 1.

This three part series on PCM-FDM compatibility has endeavored to provide the user of communications equipment with as much information as has been gathered to date by GTE Lenkurt on the problem of combining PCM and FDM within the same cable sheath. Adherence to the ground-rules laid out in this series should enable the user to systematically phase out an old FDM system while using PCM, or permanently combine PCM and FDM within the same cable sheath.

GTE LENKURT

DEMODULATOR

OCTOBER 1971


Data Modems
Data Modems
Data Modems

Modems . . . those unglamorous but vital "black boxes" that form the interfaces between digital machines and the communications network.

Modems have been referred to as data sets, line adapters, modulators, or subsets. Regardless of the name used, the purpose of each of these black boxes is to convert digital pulses into analog signals, such as audible tones, suitable for transmission over the telephone network.

If two machines – such as computers, data terminals, or facsimile machines – are communicating via the telephone network, it is necessary to have a modem at each end of the line to act as the interface between the machine and the communications line. These black boxes must be capable of modulating and then demodulating the signals – hence, the contraction modem from *mo*dulate and *dem*odulate.

A pair of modems are considered "transparent" since the signals into the first (the input) are identical to the demodulated signals (the output) from the second modem. Figure 1 illustrates the position of the modems in a data link and the signals into and out of each element of the link.

The modem and the communications line can be connected directly (hardwire) or indirectly (acoustic or inductive coupling). Acoustically coupled modems are portable since they can be used with any available telephone. With acoustic coupling, the dc data signals are converted to audible sounds which are picked up by the microphone (or transmitter) in an ordinary telephone handset. The audible signal is converted to electrical signals, and transmitted over the telephone network. The process is reversed at the receiving end.

Inductive coupling, like acoustic coupling, requires no direct connection. With inductive coupling a data signal passes to the telephone through an electromagnetic field by way of a hybrid coil.

Acoustic/inductive couplers generally do not operate as reliably as direct electrically connected modems, because they involve an extra conversion step (for example, digital to audible to electrical) where noise and distortions may be introduced. For this reason acoustic/inductive modems are presently limited to transmission speeds below 1200 bps (bits per second).

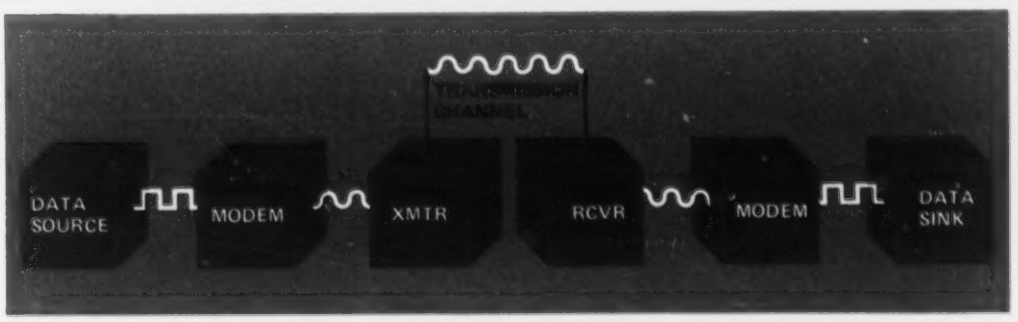


Figure 1. A data link requires a modem on each end of the transmission channel.

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A direct hook-up to the communications channel, therefore, is preferable, since it is less error-prone and not limited to low speed transmission.

Asynchronous or Synchronous

Having connected the digital machine to the communications line it is necessary to coordinate the data received with the data sent. This coordination or synchronization can be accomplished in two ways. If start and stop bits are used to "frame" each character, the transmission is asynchronous. Synchronous modems require the use of clocking devices which lock the transmitted signal of the modem and the terminal device together at a fixed transmission rate.

High-speed data generally uses synchronous transmission since for identical data coding levels and transmission bit speeds, a higher data speed can be achieved. Asynchronous transmission requires the use of two or three start- and stop-bits for each character depending upon the type of machine generating the digital signal. Consequently, if an eight-bit code is being used, asynchronous transmission requires 10 or 11 bits per character and synchronous requires only 8. Synchronous modems can therefore transmit at least 25% more characters than asynchronous modems at the same bit speed (see Figure 2).

Although synchronous transmission is efficient, the clocking mechanism requires added circuitry which makes the equipment more costly than asynchronous modems for the same speed.

Asynchronous modems have a specified maximum transmission speed, but they can be used to transmit data at any speed up to this maximum. Asynchronous modems are used for low- and medium-speed transmission up to approximately 1800 bps.

High-speed modems, on the other hand, are intended for synchronous operation at a fixed transmission rate. The transmission speed of a synchronous modem is established by the clocking source which is generally a crystal oscillator. If a synchronous modem has more than one speed, the speeds are generally multiples of the oscillator frequency.

Parallel or Serial

Another way to classify data modems is according to the type of bit stream used – parallel or serial. Figure 3 illustrates the difference between serial and parallel bit streams. Serial bit streams are most commonly used since the digital information can be modulated as it comes from the digital machine. As long as sufficient bandwidth is available for transmission without degradation, a serial bit stream may be used.

If, however, transmission is to take place over bandwidths which do not have uniform transmission characteristics, a serial bit stream can be converted to a parallel bit stream. At the receiver, a parallel-to-serial conversion

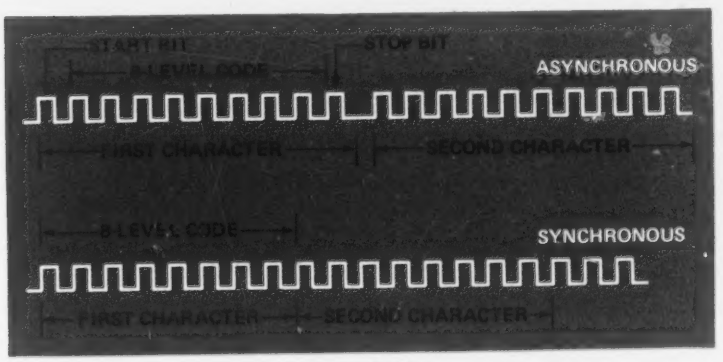

Figure 2. Each character is at least 25% longer with an asynchronous system than with a synchronous system.

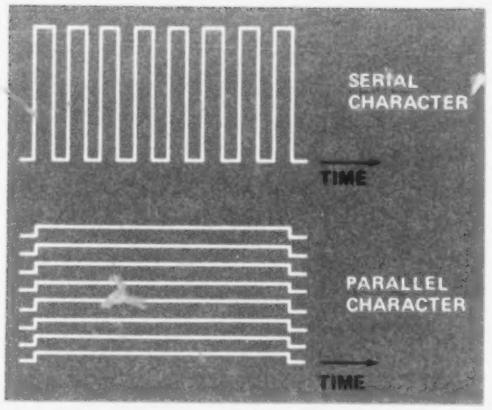

Figure 3. With parallel transmission, longer bits are used to transmit the same amount of data in a given period.

takes place. This technique is often used to transmit data at 4800 bps and higher over a voice channel.

Parallel channels with their longer symbols provide better correlation of fade and phase factors and multipath delay distortion in the propagation medium – radio or cable. (See September, 1970, *Demodulator* for discussion of transmission impairments.) However, the complex circuitry for parallel transmission makes parallel modems more costly. They are also less efficient since bandwidth is used for flanking of the bandpass filters in each channel. For these reasons serial modems have been accepted as an industry standard.

Modulation

Modems can also be classified according to the analog signal generated in the D/A (digital to analog) conversion. These analog signals may be amplitude, frequency, and phase modulated. Four types of modulation are used extensively in digital data transmission: amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), or AM combined with either FM or PM.

With an AM modem, the sinusoidal carrier wave is varied in amplitude to correspond to the digital information being transmitted. Upper and lower sidebands equal to the carrier plus the modulating signal and the carrier minus the modulating signal, respectively, occupy a total bandwidth of twice the modulation rate (see Figure 4). The entire double-sideband AM signal, a single-sideband AM signal, or a vestigial-sideband AM signal can be transmitted depending upon how the signal is processed at the receiving end.

In single sideband only, one sideband is transmitted with or without the carrier, and the required transmission bandwidth is only half that required by double-sideband AM. But, if it is necessary to transmit a dc component for signal processing, vestigial-sideband AM must be used – transmitting the wanted sideband, part of the carrier, and the low frequency end of the unwanted sideband.

Single-sideband AM gives the best bandwidth economy, but not the best equipment economy. The filtering necessary for single-sideband AM is difficult to achieve; consequently, the technique is used primarily for high-speed data transmission over a band-limited channel where the advantages outweigh the disadvantages.

Vestigial-sideband AM systems require a bandwidth approximately 1.3 times that required for single-sideband AM systems, and the technique is typically used in data modems operating at speeds of up to 7200 bps over voice-grade lines.

In AM transmission the amplitude of the carrier is varied but with FM transmission the carrier frequency varies proportionally to the instantaneous value of the modulating signal – the data bit stream. When transmitting binary data, the frequency of the transmitted wave shifts between two discrete values (determined by the channel bandwidth), one representing binary one and the other, binary zero. This is a double-sideband system called frequency shift keying (FSK) and re-

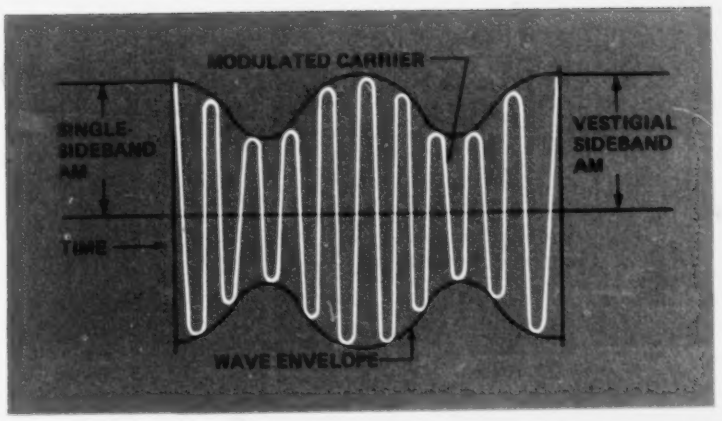

Figure 4. The wave envelope is the same as the modulating data signal. The bandwidth of the double-sideband AM signal is twice the bandwidth of the modulating signal.

quires approximately the same bandwidth as double-sideband AM.

For phase modulation the phase of the transmitted carrier varies proportionally to the instantaneous value of the modulating signal. For binary data transmission the phase is shifted 180° for each transition between one and zero, or zero and one. Phase shift ' ying (PSK) is extensively used for synchronous high-speed data transmission systems up to 2400 bps. However to transmit at 2400 bps and above, it is necessary to resort to a four-phase system utilizing 90° shifts. PSK, like FSK, is a double-sideband system.

In a special form of FSK called duobinary, FSK modulation is used in conjunction with duobinary coding which uses a three-level code to represent the binary data. The duobinary coding technique, developed at GTE Lenkurt, is used in the GTE Lenkurt 26C data modem. Assuming a constant bandwidth data channel, duobinary FSK transmits at twice the speed of FSK. Figure 5 shows the difference between FSK and duobinary FSK.

Factors to consider when selecting a modulation scheme are complexity of electronic circuits, required bandwidth, quality of transmission channel, signal-to-noise ratio, tolerance to delay distortions, tolerance to amplitude changes, tolerance to jitter, and reliability. Each system has some advantages relative to the other systems.

Compared to Voice Band

Another way to classify modems is by their required transmission bandwidth. Modems can be divided into three categories: sub-voice, voice, and greater-than-voice band (or wideband). The chart in Figure 6 relates bandwidth to transmission speed, and illustrates that transmission speed is generally proportional to bandwidth.

Sub-voice band modems use only a fraction of the 4-kHz voice band for each data channel. These modems generally serve slow digital devices with speeds of up to 600 bps. Frequency division (FDM) or time division (TDM)

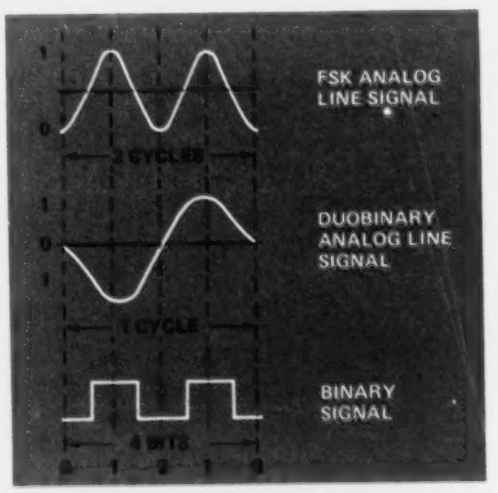

Figure 5. Duobinary FSK transmission is twice as fast as FSK transmission showing four binary bits compressed into one cycle of the line signal.

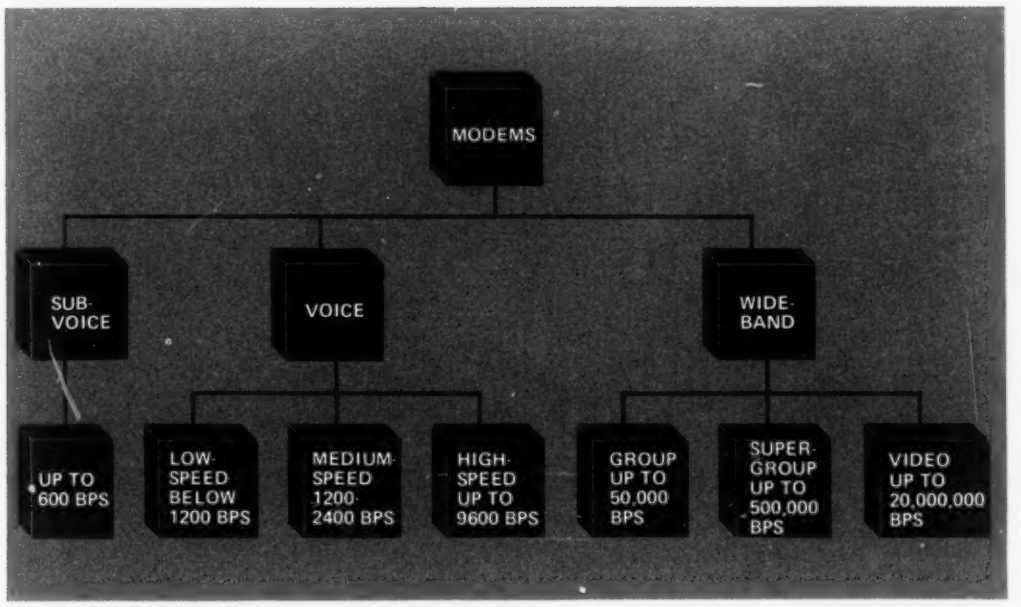

Figure 6. Bandwidth and transmission speed are generally related as shown in this chart – the wider the bandwidth, the higher the speed.

multiplex techniques are used to fill the voice band. With FDM, a multiplexer is not needed because the modem conditions the data signal for transmission in its proper frequency slot on the telephone line – the signal is in essence frequency modulated and translated. GTE Lenkurt's 25C data modem performs such a multiplexing function. But, with TDM, a multiplexer combines the digital signals in time. This new high-speed, serial bit stream then goes to a modem for digital to analog conversion and transmission over the telephone circuit. Figure 7 illustrates the difference between FDM and TDM systems.

FDM and TDM are equally suitable for voice grade channels. However, TDM is more efficient in bandwidth utilization; therefore, more channels can be multiplexed on a single channel. Conversely, FDM is best suited where few circuits are dropped off and picked up at scattered points, and where the greater reliability of individual channel modems is desired.

Since voice band modems range in speed from as low as 300 up to 9600 bps or higher, they are not defined as much by speed as by the facility and means of transmission. Voice band data is the most efficient means of utilizing the telephone network.

Satisfactory modem performance at 3600 bps and above generally requires complex equalization circuitry to pre-condition the signal for non-linear or varying line parameters – such as delay distortion and attenuation. Some high-speed modems, generally used over leased lines with relatively constant characteristics, use manually adjusted equalizers. Other high-speed modems use automatic or adaptive equalizers to continually adjust to the line characteristics.

Medium-speed voice band modems operating in the 1200- to 2400-bps range have been in general use for over ten years and have achieved a degree of reliability and low-error performance adequate for most data transmission applications. Most of these medium-speed modems tolerate or pre-condition the signal for minor changes in telephone line characteristics without error or interruption of

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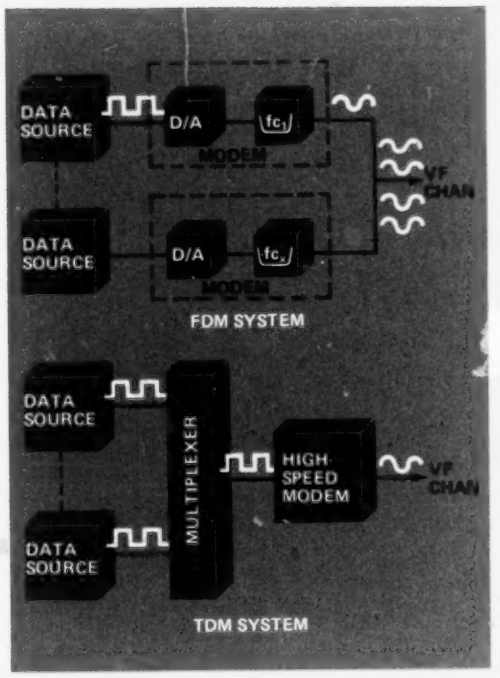

Figure 7. A time division multiplex system requires the use of a multiplexer and a modem.

transmission. Medium- to high-speed modems at 4800, 7200, and 9600 bps are finding wider use as transmission speeds continue to increase.

The telephone network is designed such that when the signal bandwidth exceeds one voice channel, the next transmission channel has a group bandwidth or supergroup bandwidth – equivalent to 12 or 60 voice channels. Greater-than-voice band or wideband modems operate at speeds from 18,750 to 500,000 bps. Top speed is presently limited by the expense of leasing wider bandwidths and the limited need to move much larger volumes of data at these rates.

Wideband modems are not true modems since they do not contain a modulator or demodulator, but they do condition a digital signal for transmission over the telephone network. In wideband data sets, the digital signal is first put through a scrambler which inverts every other pulse to eliminate sustained intervals of ones or zeros that might create an undesirable dc component in the line. Next the signal is filtered to remove low- and high-frequency components. The result is an ac signal which, for 50,000 bps data, has a 25-kHz fundamental frequency – since two bits complete a cycle, the fundamental frequency is half the bit rate. There is no need to translate the wideband signal in frequency, as there is for sub-voice and voice band modems.

This ac signal readily passes through transformer-coupled circuits and over non-loaded physical cable pairs with reasonable equalization and amplification. The signal can also be fit into a twelve-channel bandwidth for analog exchange and trunk carrier systems.

High-speed modems may be frequency division multiplexed to put a number of them in parallel on a single wideband circuit.

The great advantage of digital transmission via wideband systems is that high data transmission rates may be obtained while keeping the data stream in serial form. In the multiplexing equipment it is not necessary to come down to the nominal voice channels (4-kHz), but the serial data streams may be modulated on a group bandwidth (48-kHz) with a data rate capability of 50,000 bps, or a supergroup bandwidth (240-kHz) at up to 500,000 bps.

All-Digital Network

All-digital transmission networks which would not require data modems are being designed, developed, and tested, but it will be a long time before the sub-voice and voice band data systems requiring modems are eliminated from the telephone network – if they ever are.

GTE LENKURT

DEMODULATOR

NOVEMBER 1971

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FOR DATA TRANSMISSION

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The envelope delay and frequency response of a voice channel must be controlled for acceptable, high-speed data transmission.

A digital communications system is typically made up of a digital source such as a computer, a data modem that "conditions" digital signals for transmission over voice telephone lines, the telephone transmission line, and a receiving terminal with a modem and a data sink. The transmission line, which may be one or a combination of many transmission media such as microwave or coaxial cable, may be leased from the telephone company on a dedicated, private-line basis or through the switched telephone network.

In leasing a line, the potential user must first determine his data requirements in terms of transmission speeds and number of channels. A chart similar to the one shown in Figure 1, can be used to determine the data channel-allocations on a voice line and if it is necessary to condition the line for acceptable transmission. For example, it is necessary to have C2 conditioning to transmit 11, 150-bps channels over a single line.

A voice circuit or line can transmit a limited amount of data without special conditioning. But as data transmission speeds increase, the bandwidth required for each data channel also increases and fewer data channels can be transmitted on an unconditioned line. Conditioning a voice line provides a wider band of frequencies for data channel-allocation by adding equalizers that reduce the deviation in envelope delay and frequency response.

Line conditioning provides a certain level of envelope delay and frequency response on a voice circuit. Other transmission parameters such as impulse noise and phase jitter are not affected by line conditioning, but may need to be controlled.

Envelope Delay

During transmission some frequency components of a signal are delayed more than others. This phenomenon, illustrated in Figure 2, is called envelope delay distortion since it distorts the envelope of a multi-frequency signal. At low frequencies in a voice-frequency transmission facility, envelope delay is primarily caused by inductive effects of transformers and amplifiers in the total system. The capacitive effects are the primary cause at high frequencies. In carrier transmission facilities, the filters in the channel equipment also cause envelope delay.

Envelope delay must be equalized when the delay begins to interfere with the intelligibility of the signal. The human ear is relatively insensitive to the effects of envelope delay, so equalization is not needed for speech transmission.

Digital signals, on the other hand, can be misunderstood if the effects of envelope delay are not corrected. Data

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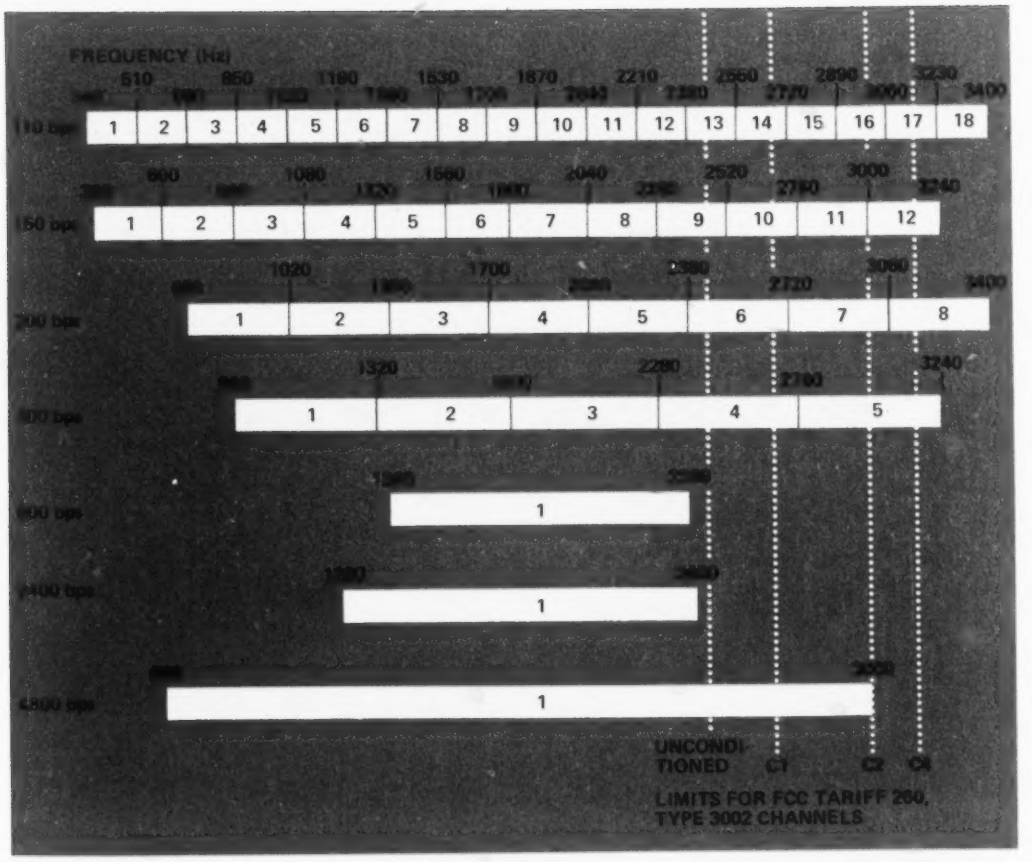


Figure 1. Data channel allocations and the necessary voice channel conditioning can be seen from this chart.

bits usually originate as rectangular-shaped pulses which are used to modulate a carrier at a particular keying rate for transmission over a communications circuit. The AM or FM signals used in transmission are composed of many frequencies.

If such a multi-frequency signal passes through a circuit with a non-uniform delay characteristic, it becomes severely distorted. In fact, the signal energy may "spread out" to the point where the original signal is no longer intelligible.

When considering the cause of delay distortion, it should be noted that an appreciable impedance mismatch between line sections, or between the line and the office apparatus, will also influence the delay characteristics of the facility.

Frequency Response

An ideal data communications channel has a flat frequency-response throughout. Some frequencies within the typical 4-kHz voice channel are attenuated more than others; consequently, the voice channel is not an ideal data channel. But, any multi-frequency communications channel exhibits this varying frequency attenuation, known as attenuation distortion.

This non-flat frequency response takes the form of band-edge roll-off and in-band ripple. An ideal transmission channel would have sharp cut-off frequencies, but band-edge roll-off re-

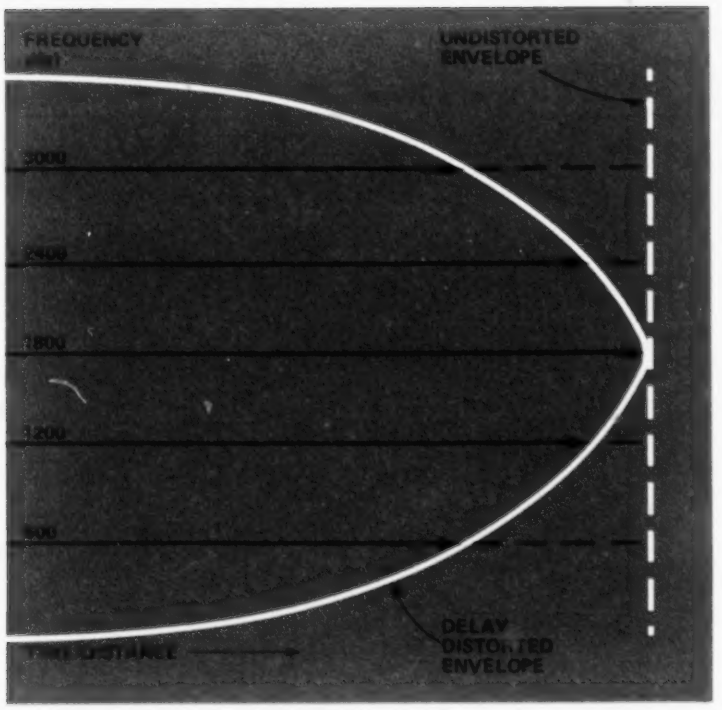


Figure 2. With envelope delay distortion, the frequency components of a signal travel at different speeds.

sults in the frequency response gradually diminishing at the edges of the band. Band-edge roll-off is usually caused by the characteristics of the bandpass filters in a voice multiplexing system, by the low-pass characteristics of loaded cable, or by the high-pass characteristics of transformers and series capacitors. In-band ripple which results in non-uniform frequency response in the middle of the channel is caused primarily by impedance mismatches throughout the system.

Frequency response is usually corrected at the receiving end of the circuit. An exception would be in cases where intermediate switch locations occur in long-haul circuits that can be separated into shorter segments for switching. In such cases, for purposes of equalization, each segment is treated as a separate circuit. In a dedicated network, conditioning may be applied at each transmitter location.

In the switched network rather than a dedicated network, compromise equalization effectively compensates for band-edge roll-off since all channels experience similar roll-off, regardless of how a channel selection is made. In this case the equalizer is adjusted to compensate for typical roll-off characteristics. The resulting equalized response will not be exact for every possible circuit connection, but it will generally be satisfactory throughout most of the network.

Conditioning

When a voice line is leased from the telephone company for data or alternate voice/data transmission, it is possible to specify the degree of line conditioning desired. In this case the telephone company is responsible for the quality of the line and guarantees that the line meets the FCC specifications for the desired level of conditioning. The specifications for envelope delay and frequency response for each degree of line conditioning are shown in Figure 3.

When the telephone company furnishes the modem and subsequent line conditioning to establish a data transmission system, the expected long-range error rate performance under normal conditions is one error in 100,000 bits (or an error rate of 10^{-5}). When the user leases an unconditioned or conditioned line for use with his own data system, he is responsible for the system's overall performance. Therefore, it is the responsibility of the customer to decide what conditioning arrangement is needed for his data transmission system.

If an unconditioned line is leased, the user, as a result of the Carterfone decision of 1968, may condition the line himself. By purchasing his own equipment, the user may condition the line for his desired service.

The types of conditioning that are available from the telephone company for standard 3002 voice lines are C1, C2, C4, C3, and C5, listed in increasing quality. The table in Figure 3 shows the differences in these line conditionings. The C5 conditioning was recently established for serial data speeds of 9600 bps and above.

Regardless of the level of conditioning used it is normally desirable to select channels from the middle of the band. This minimizes the effect of envelope delay and attenuation which are more severe at the edges of the voice channel.

When determining what type of service to lease from the telephone company, the user should consider the various options available. For example, a user who presently has a C1-conditioned line and is transmitting nine channels of 150-bps data, may find he has a requirement for 2 additional channels at 150 bps – or a total of 11 channels. Referring to Figure 1, there are three options available.

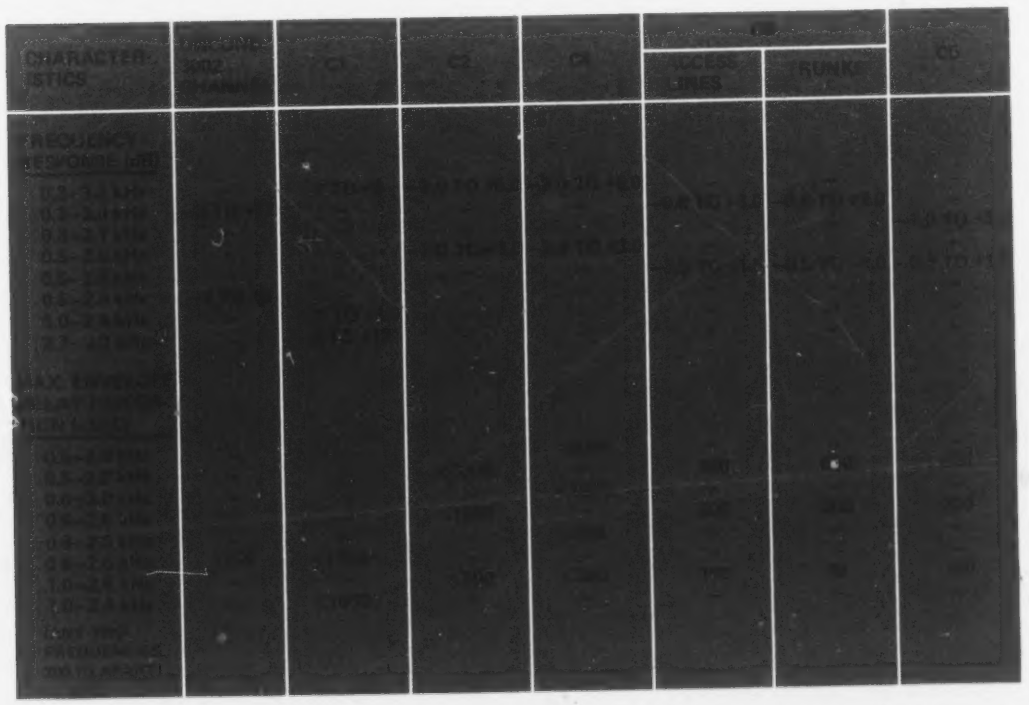


Figure 3. Each degree of line conditioning provides tighter specifications on envelope delay and frequency response.

First, the line can be conditioned for C2 or C4, to provide for additional future channels. Second, a new unconditioned line could be leased in addition to the existing C1 line. Or third, the conditioning on his present line could be removed and another unconditioned line added. The cost of leasing these different options will vary and the user must decide which is the most economical for his present increased needs and perhaps his future needs.

A line is conditioned to improve its transmission capability. With a leased, dedicated, private-line facility, it is possible to determine the envelope delay and frequency response characteristics in the system. Then depending upon the speed of data to be transmitted over the facility and the number of channels required, it is possible to condition the line to compensate for the distortions introduced by the facility. The higher the speed of transmission, the fewer distortions that can be tolerated by the data signal.

Switched Network

The switched telephone network (the standard dial-up voice network) provides a totally different picture as far as data transmission is concerned. Since slow-speed data such as telegraph can be transmitted over an unconditioned line, there is no problem with using the switched network. But for higher speeds or greater capacity low-speed systems, a switched network can prove to be unsatisfactory since it is not possible to predict the route the signal will take and consequently the distortions it will be subjected to.

Use of the switched telephone network for high-speed data communications can be summed up in one word — unpredictable. With a dedicated system it is possible to determine the

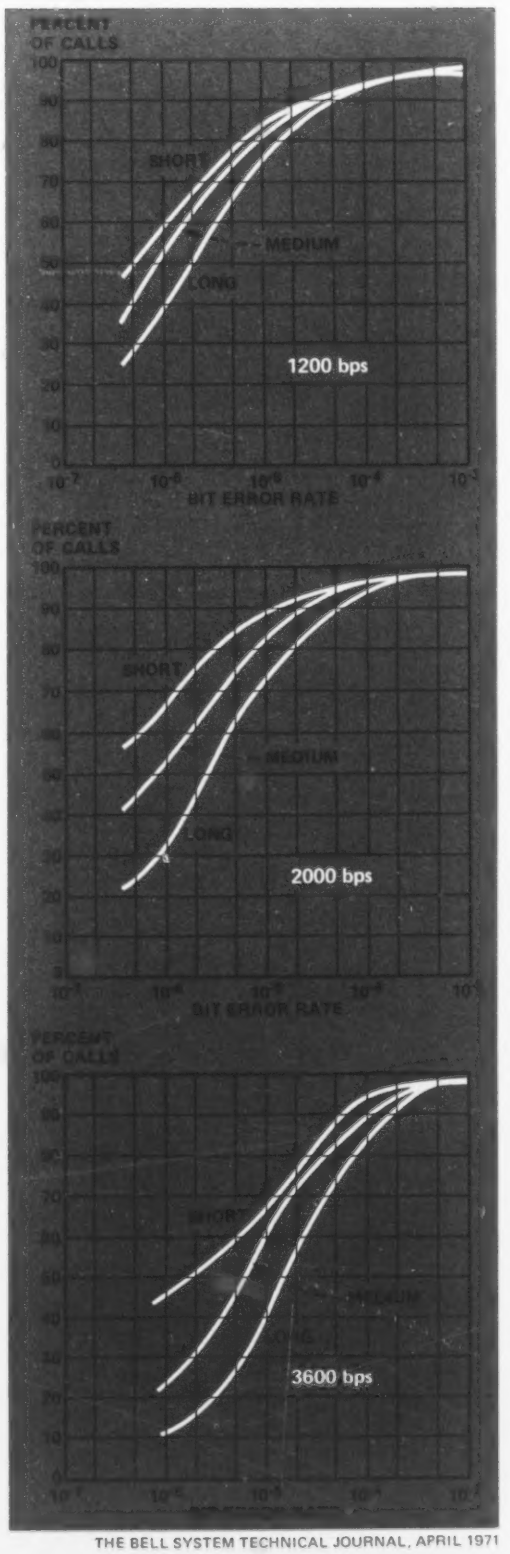


Figure 4. The results of a statistical study are used to predict performance on the switched network.

performance on the line and then compensate for the envelope delay and frequency response. With the proper equalization, it is possible to keep these characteristics within tolerable levels for the desired transmission speeds.

But on a switched network, it is not possible to predict the exact route the data signals will take between central offices before it gets to its destination. Consequently, it is not possible to predict the distortions that the signal will be subjected to. What is possible, is to take a statistical sampling of signals sent over the switched network and determine the average performance of the network. It is then possible to design compromise equalizers that will compensate for average delay and attenuation distortions.

A compromise equalizer cannot be used to guarantee a certain level of conditioning. This means that for some of the routes the compensation will be greater than necessary and for other routes it will not be great enough.

With data up to speeds of 600 bps, it is not necessary to compensate for envelope delay and frequency response on a switched network. GTE Lenkurt's type 25 data modems work quite satisfactorily on the switched network.

As transmission speeds increase, the number of lines within the switched network, suitable for acceptable transmission, decreases. Therefore, the percentage of suitable circuits decreases and the probability of having an "error-free" transmission also decreases.

With compromise equalizers it is possible to have 80-90% of the circuits suitable for transmission speeds of up to 2400 bps. The GTE Lenkurt 26C data modem can be equipped with a compromise equalizer for use over the switched network.

The telephone companies also provide compromise equalizers. Such equalizers are used on the leased line from the terminal to central office which connects the user to the switched network.

On a dedicated line envelope delay and frequency response are the most important transmission parameters that the user has to be concerned with. But, with the switched network there is another area of concern – impulse noise (voltage spikes or transients). Each switching office along the data path introduces more impulse noise on the line. On a switched network it is possible to have some routes that are unsatisfactory for data transmission because the impulse noise gets too high and too frequent.

Figure 4 shows the predicted error rate for different data speeds through the switched network. These curves, which are the result of a Bell Labs study, take into consideration envelope delay, frequency response, impulse noise, and other impairments that might show up on a random sampling of the switched network.

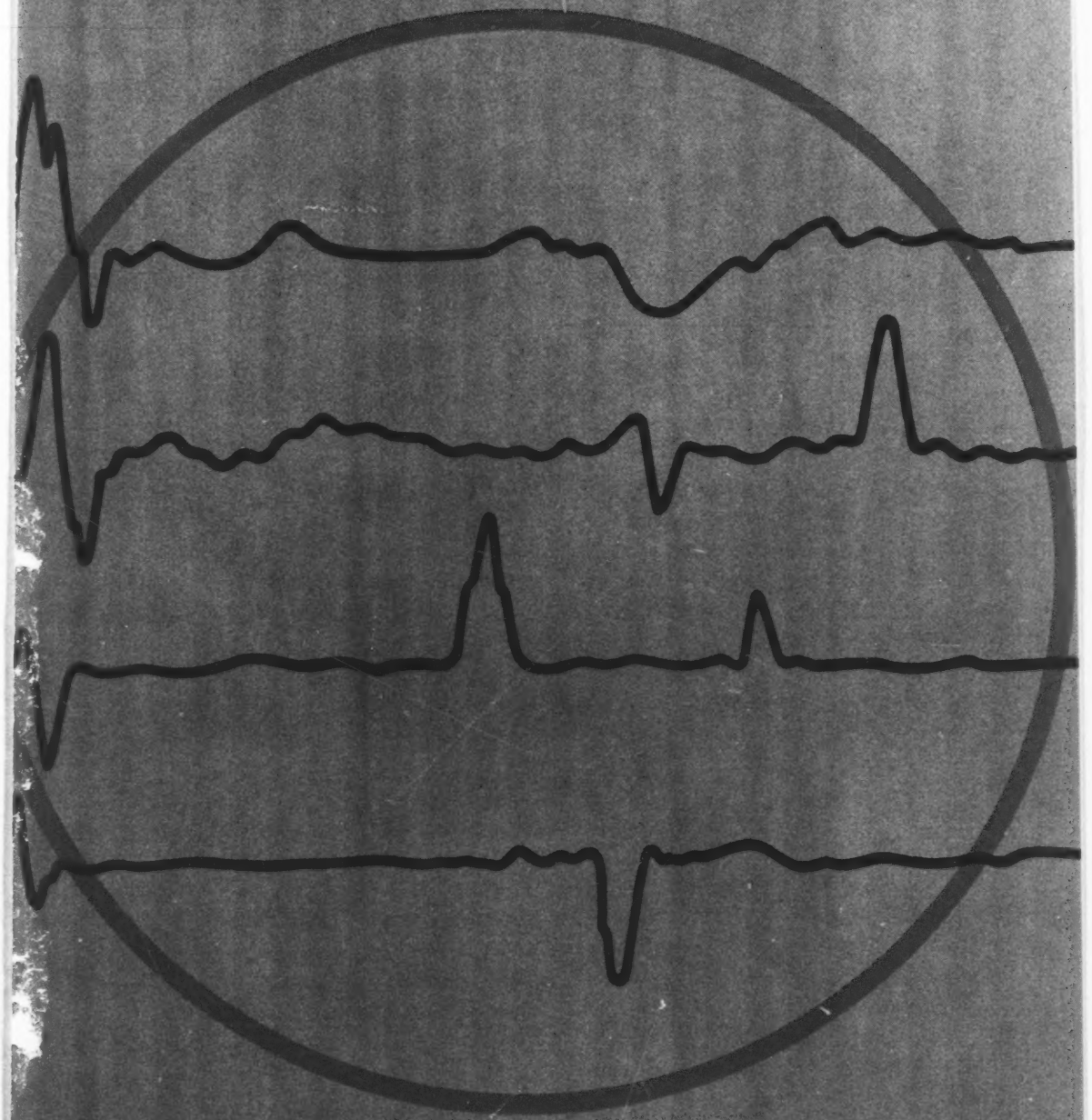
Specific or Compromise

Whether the user wishes to use a dedicated, private telephone line, or a line into the switched telephone network, it is possible to equalize the line so that a high degree of reliability can be achieved in his data transmission system. This line equalization can be done with either specific C1, C2, C4, C3, or C5 line conditioning or compromise equalizers.

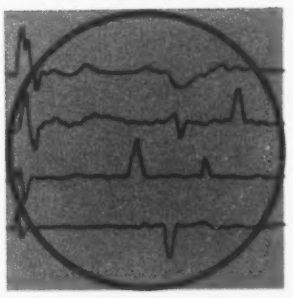
GTE LENKURT

DEMODULATOR

DECEMBER 1971



CABLE TESTS AND MEASUREMENTS FOR PCM



For the user of communications equipment who is contemplating connecting new equipment to cable that has already had considerable service, it is wise to be sure that existing lines are in acceptable condition.

New equipment has on many occasions been connected to older cable resulting in an unsatisfactory system. In a situation such as this, if only part of the total number of channels function properly – what is at fault, the cable or the equipment? Because it is difficult to reliably estimate the overall condition of older cable without testing, this question can only be answered after a complete series of tests and measurements have been performed on the cable.

Because of its period of usage, deterioration of older cable may result in such faults as shorted cable pairs or moisture within the sheath. To detect faults such as these, measurement of each cable pair is still the ideal method of operation. Although the measurements discussed here tend to favor testing for PCM, they are suited for all types of carrier operation.

The use of cable pairs for PCM or any other type of carrier service requires that they be free of loading coils, building-out networks, crosses, splits, high resistance splices, grounds, moisture, bridged taps, and cable terminals bridged across pairs (when subscriber cable is used). Should a bridged tap, loading coil, or building-out network scheduled for removal be overlooked when reading a cable location map, subsequent visual observations may completely fail to detect it. For this reason, pulse reflection tests using a radar test set are recommended when the presence of any of these external additions is suspected. Additional tests which help to evaluate the overall condition of a cable include:

(1) DC loop resistance and conductor resistance balance test using a Wheatstone bridge.

(2) Insulation resistance measurement using a megger test set.

(3) Frequency response test to 1 MHz using an oscillator and frequency selective voltmeter.

Radar Cable Test Set

The radar cable test set is an invaluable tool in detection of cable discrepancies and attached networks. The test set, as its name implies, operates on the simple principle of pulse reflection. The nature of the return pulse reveals the type of discontinuity present in a cable. For example, a positive (upward) deflection on the test set oscilloscope trace indicates an open circuit or high impedance mismatch while a negative deflection indicates a short circuit or low impedance mismatch. A shorted pair returns a strong negative pip at the point of short circuit since almost all energy is returned from the fault. A good cable pair will show either no reflection or an open (positive pulse) providing the end of the cable is within the range of the radar test set. In addition to

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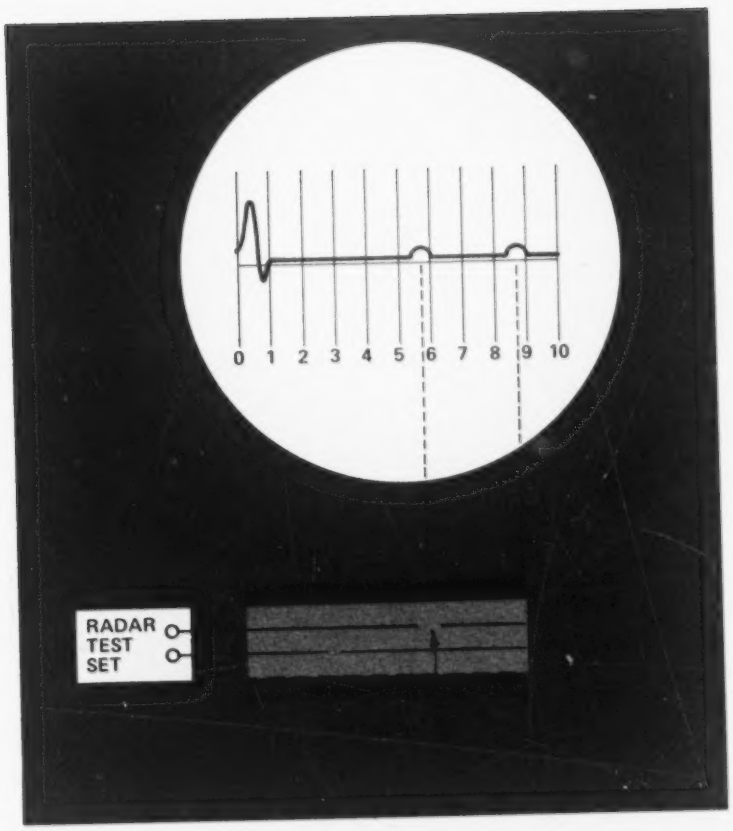


Figure 1A. A pair with one conductor open will show a positive return pulse.

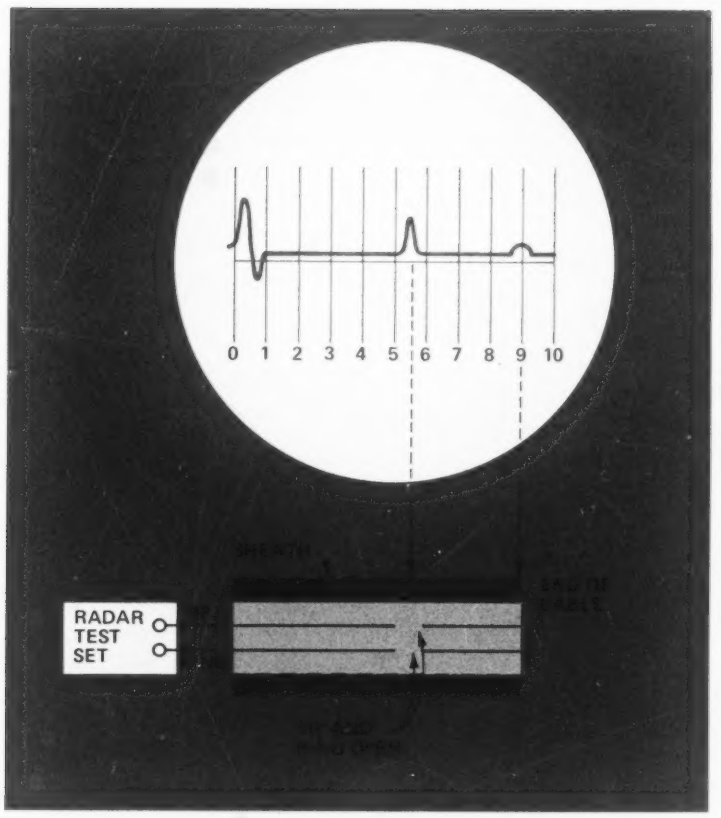
revealing the nature of the discrepancy in a cable, the radar test set can also show the actual distance to the point of fault.

Although the operation of a radar test set is relatively simple, some experience is necessary on the part of the operator in the interpretation of the return signals. For example, a negative return pulse displayed on the oscilloscope of the radar test set for two separate cable pairs does not necessarily mean that the cable pairs have similar discrepancies. The method of detection in this case would be to notice the amplitude of the return pulse since different amplitudes indicate different cable faults.

Open Conductors

An open in either conductor will result in a positive pulse on the oscilloscope screen although of lesser amplitude than if both conductors were open. Figures 1A and 1B show the oscilloscope display as it would appear with one and two conductors open. Also shown are the corresponding cable pair and sheath with the appropriate conductor designations. The reflection from the end of a cable may sometimes be observed in spite of an open in one of the conductors, but this depends upon the closeness of the fault to the end of the cable and upon the size of conductor used. Telephone communications lines generally use cable which ranges from 16 to 26 gauge; the attenuation of the cable increases in direct proportion to the gauge number. The return pulses in 26-gauge cable are the weakest since this gauge has the greatest attenuation due to its higher resistance. Testing

Figure 1B. When both conductors are open the return pulse will be of greater amplitude than that for one conductor open.



a 26-gauge conductor, the maximum fault location distance is about 4000 feet. For greater distances (8000 to 10,000 feet) a special pulse amplifier must be used to see the return signal.

Historically, the tip (T) and ring (R) designations were so called because they corresponded to the contacting part at the tip and ring of the phone plug used to make circuit connections in a manual switchboard. Today, the designations tip (T) and ring (R) are used to identify the two conductors of a cable pair. The sleeve of the plug is used for certain control functions, not directly associated with the cable pair.

Loading Coils and Building-out Networks

The function of a loading coil is to increase line inductance and thereby improve transmission characteristics. As shown in Figure 2, the tip and ring conductors connect to separate windings on the donut-shaped core. The two coils are wound in a direction that produces an aiding magnetic field. A cable which runs between two points is engineered according to a predetermined loading plan. For example, an H88 loading plan requires 88-millihenry coils to be placed at 6,000-foot intervals along the cable.

If for some reason, be it geographical obstruction or inconvenient location, a loading coil cannot be placed in the designated area, a building-out network is used to artificially make up the required distance (6000 feet in the case of H88 loading). The building-out network consists of resistors and capacitors connected in such a way that electrically, the distance between load-

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ing coils conforms to the required loading plan. That is, the building-out network contains the resistance and capacity inherent in the length of cable necessary to conform to the loading plan. Loading coils and building-out networks must be removed from the cable before it can be correctly evaluated for use.

Open Sheath Detection

A high-frequency pulse such as is emitted from the radar test set will usually be prevented from passing through a loading coil by the choking effect of inductance on high frequencies. However, using a certain hookup procedure, the radar test set may be made to measure beyond loading coil points.

Individually, the tip and ring windings of the loading coil will have a nullifying effect on a high frequency pulse, but when the pair conductors are connected together, this effect is counteracted to some extent.

To detect an open sheath, one or more cable pairs which have been tested and found to be serviceable must be connected in parallel to one terminal of the radar test set; the other terminal is connected to the cable sheath. In this way the effect of the loading coils is cancelled and the test pulses can pass beyond the attenuating inductance. Figure 3 shows the radar test set hookup and corresponding oscilloscope display for open sheath detection.

Grounded Sheath On Buried Cable

When cable is buried by means of a cable plow, the surrounding earth will remain loose, thus creating a void around the cable. With the passage of time a gradual repacking takes place and the void is eliminated. Should a grounded sheath exist during a void environment, detection of the fault is possible provided the void is filled with water such as occurs in an area with a high water table or after a rainfall which has heavily wetted the ground.

Plowed cable normally disturbs the surrounding earth to such an extent that the sheath-to-ground capacitance is non-uniform. This causes sufficient variation in capacitance to make propagation of the radar pulses difficult. However, when the void is filled with

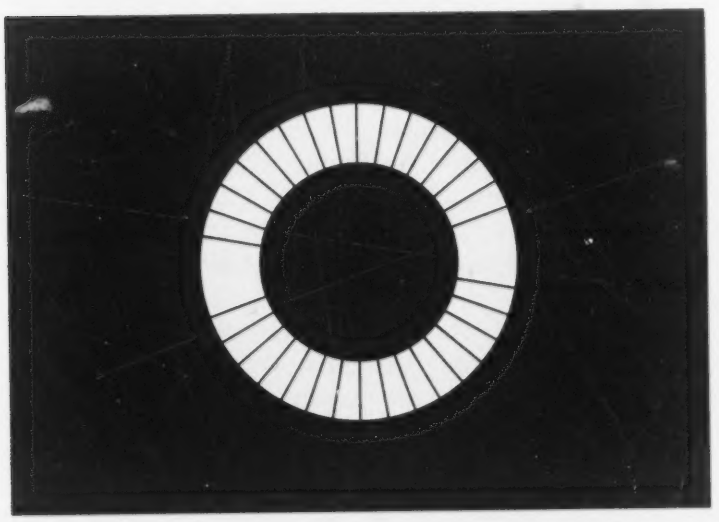

Figure 2. Loading coil with corresponding tip and ring connections.

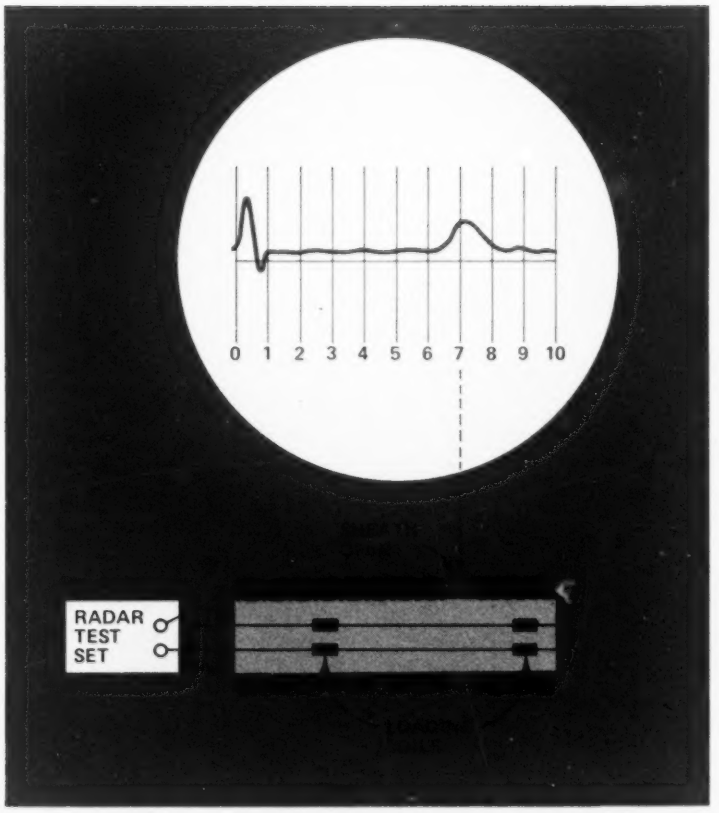

Figure 3. Display and hookup for open sheath detection.

water, or earth conductivity is low (40 to 50 ohms), the capacitance tends to become more constant, and a pulse may be returned with sufficient strength to be visible. Figure 4 shows the grounded sheath oscilloscope display with the corresponding test set connections.

Cable Splices

Due to the change in relationship between cable pairs and the sheath, a splice represents a decrease in capacitance, and will appear as a small rounded positive pip (radar return pulse) followed by a small negative pip on the oscilloscope trace. At times, the negative pip may not appear. A known splice may be used as a reference point for calibration when performing measurements in a cable of unknown dielectric constant.

Crosses

Metallic crosses (short circuits) between pairs present somewhat the same indication as a short to the sheath. Since a metallic cross is usually a solid connection it may seem that the easiest way to find the other pair or conductor involved is by performing a standard battery and earphone test. However, since the radar test set indicates the distance to the trouble, once the sheath is opened the trouble can be found visually.

Crosses due to moisture in the cable appear as an extremely noisy trace with a vertical displacement of the entire trace throughout the wet section, as shown in Figure 5. Any reference points, such as splices within the wet area will appear farther apart than normal. Ranges in the wet area will appear approximately 60% greater

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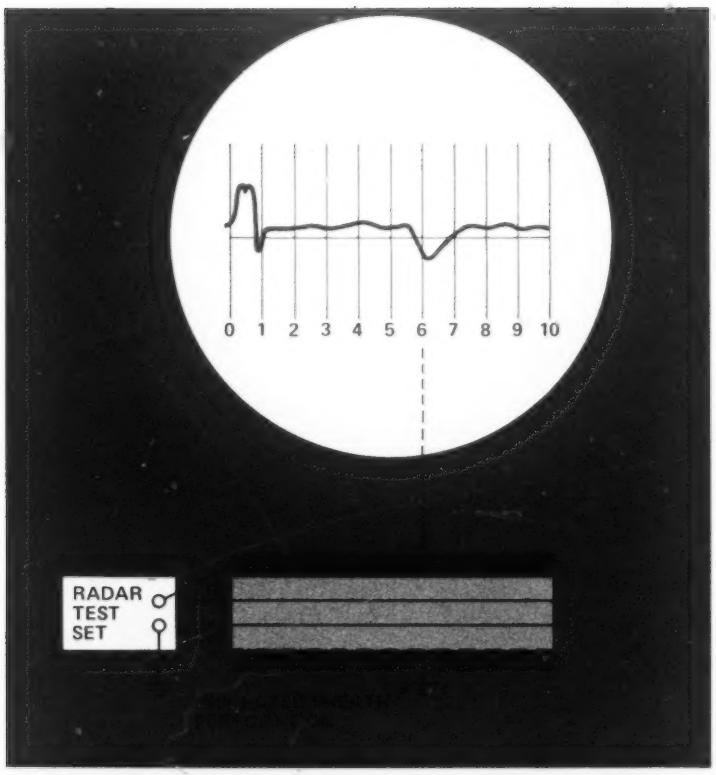


Figure 4. Grounded sheath on buried cable.

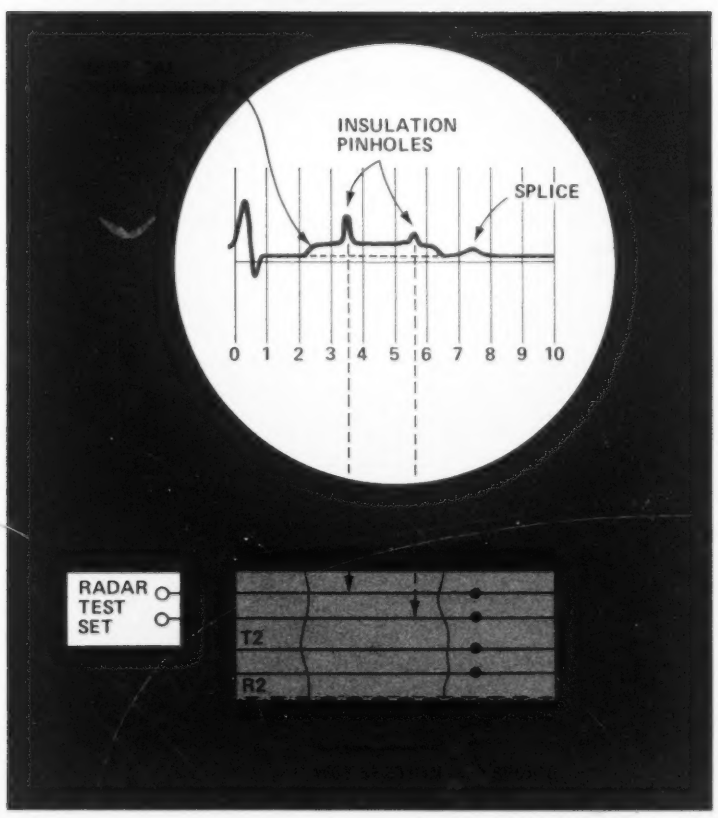


Figure 5. Crosses due to moisture appear as an extremely noisy trace with a vertical shift.

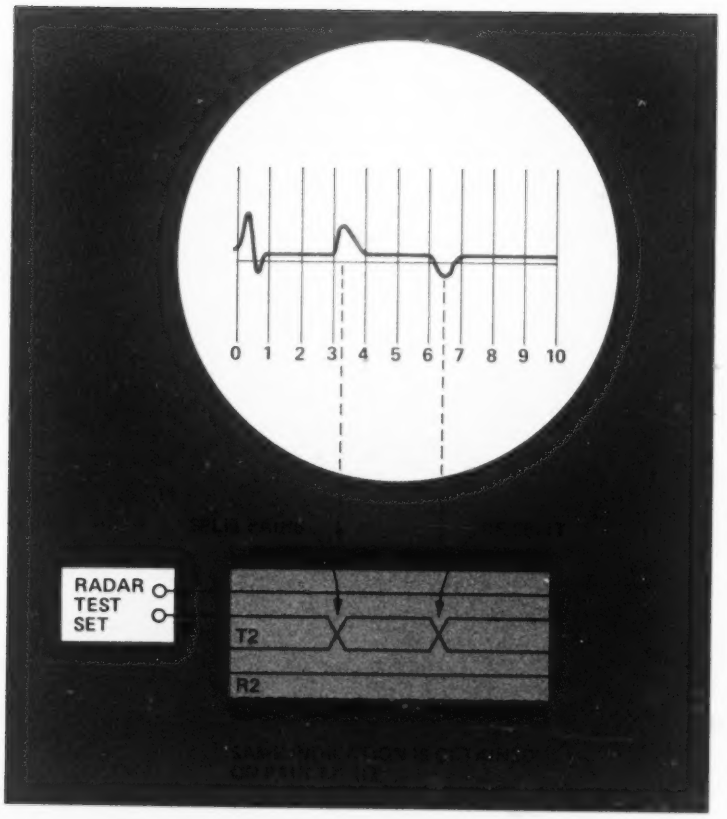


Figure 6. A split pair on a cable causes a decrease in capacitance and a positive pulse on the scope.

than the reference distance if the fixed Polyethelyne Dielectric setting on the radar test set is being used. This setting takes into consideration only dry PIC cable, the PVC (propagation velocity constant) of which is 0.667. This velocity constant means that high-frequency signals in the cable will travel only 66.7% as fast as they would travel in free space. The retardation effect caused by the higher dielectric constant of water decreases the propagation velocity of the pulse, yielding a slower traverse of the pulse through the wet section. To accurately measure the distance within the wet area, the Cable Dielectric Switch on the radar test set may be manually adjusted until a known reference point such as a splice is correctly positioned. The correct distance may now be read in spite of a change in PVC. The propagation velocity constant of wet cable is approximately 0.400.

Split Pairs

A split occurs at a splice when the tip or ring of one cable pair is accidentally spliced to the tip or ring of a different cable pair. Without the radar test set, the location of a split is often very difficult to find, especially on buried cable. The oscilloscope presentation for a split will show a capacitance discontinuity similar in form to that of a splice at the point where the conductors are separated. That is, a decrease in capacitance will be indicated by a positive pip as shown in Figure 6. If a re-split (restoration to normal condition) occurs in a subsequent splice, the pip will appear with the opposite polarity of that shown for the split.

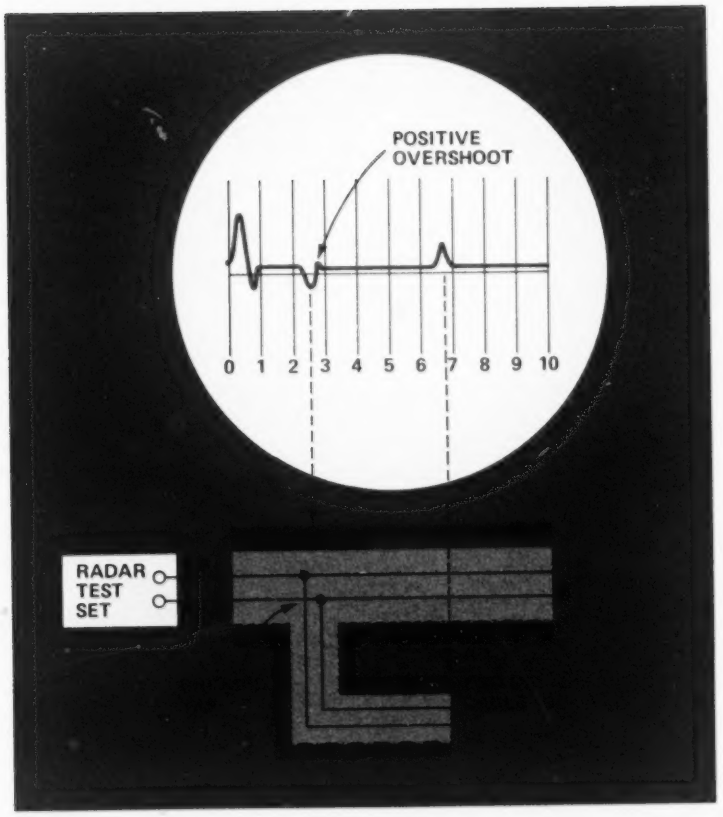


Figure 7. Bridged taps appear as negative pips with a positive overshoot.

Bridged Taps

For any type of FDM or PCM carrier operation, bridged taps must be removed since they represent a capacitance mismatch at high frequencies. These taps appear as negative pips, having a negative amplitude with a following positive overshoot or tail as shown in Figure 7. The amplitude of the overshoot is directly proportional to the length of the tap. Generally three or four taps with an average length of 100 feet will absorb all the output energy of the test set. In order to verify that all bridged taps are removed, it is necessary to repeat the test from the location of the last removed tap. A bridged cable and the main cable will present an overlapped trace. If a fault (short, cross or ground) also exists on the same cable pair, measurement from two locations is necessary to determine positively the location of the fault.

Loading Coil and Building-Out Network Detection

Loading coils and building-out networks that have been overlooked in the process of deloading a cable for carrier use, are perhaps the most difficult things to locate without the aid of an instrument such as a radar test set. A building-out network will appear on the oscilloscope display as a short circuit (the capacitors in the network short-circuit the radar pulse) and a loading coil appears as an open circuit since the pulse will not pass through the coil (see Figures 8 and 9).

Change in Wire Gauge

An increase in wire size such as at a splice decreases the resistance of the

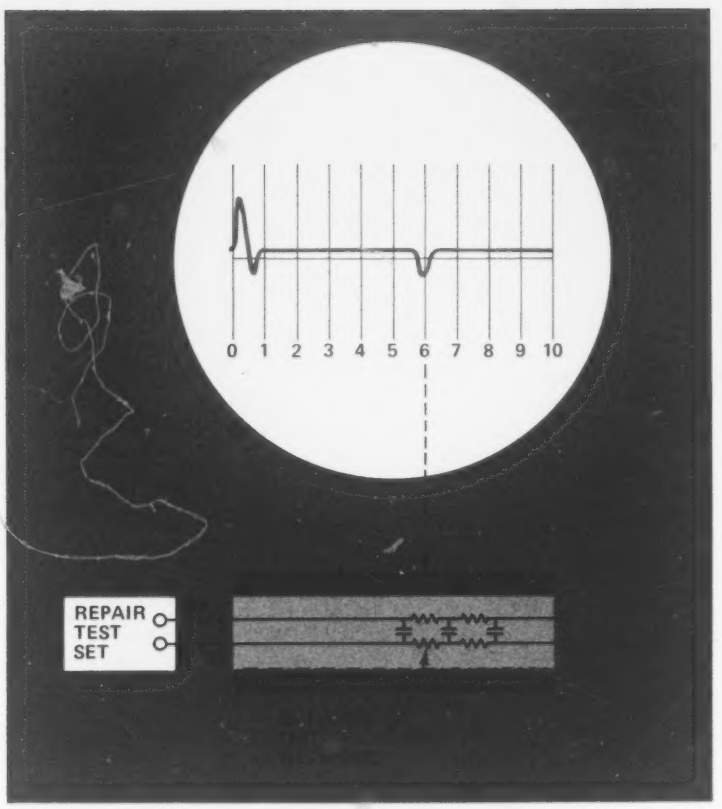


Figure 8. Building-out networks appear as short circuits.

line and will give a negative pip similar to that of a bridged tap, but of lesser amplitude. The propagation velocity constant varies by approximately 1% per gauge number. (A change from 22 to 24 gauge will change the PVC by about 2%.)

Change in Dielectric Material

A change from PIC to PULP (paper insulation) cable will also cause a reflection indication. In this case, the propagation velocity constant will increase, producing a decrease in surge impedance, thereby yielding a negative pulse on the oscilloscope screen. The resultant pip amplitudes are generally small, less than those caused by bridged taps. If the dielectric constant of the insulation is known, the change in propagation velocity constant can be calculated by the formula:

$$\Delta PVC = \frac{1}{\sqrt{e}}$$

where e is the dielectric constant.

DC Loop Resistance and Conductor Resistance Balance

This test is advisable to verify the correctness of loop resistance and conductor resistance balance, which is necessary for proper carrier operation. Because the allowable resistance variation between conductors in the conductor resistance test is a maximum of ±0.5%, it is necessary to use a Wheatstone bridge since its accuracy is dependable within this tolerance. Measured loop resistance should check within 10% of the calculated values given in Figure 10. Due to the relatively wide tolerance in the loop test, and the fact that the balance test is a comparison measurement, it is permis-

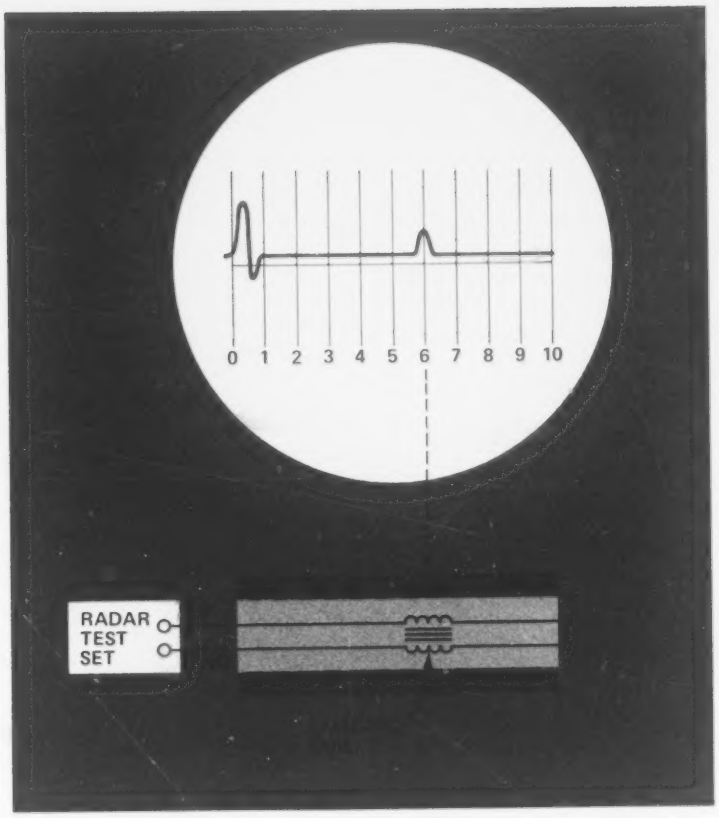


Figure 9. A loading coil appears as an open circuit.

sible to neglect the effect of temperature on the wire resistance.

With a Wheatstone bridge connected to the pair to be measured and a short-circuit placed across the distant end of the pair, the hookup will appear as in Figure 11A. The loop resistance should be within the required 10% tolerance of the calculated values given in Figure 10, noting that this is the total resistance "out and back." Removal of the short circuit at the distant end should indicate an open circuit. This step is necessary to verify that the pair being measured actually had a short circuit placed on it, and was not showing a loop due to some other connection.

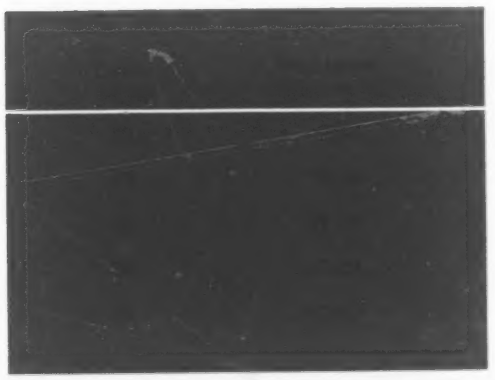


Figure 10. Total "out and back" conductor loop resistance.

Example:

Assuming that 6200 feet (6.2 kft) of 22 gauge cable is used in one regenerator (repeater) section,

Loop resistance
= 6.2 kft x 32.28 ohms/kft
= 200.14 ohms.

Figure 11A. Loop resistance measurement.

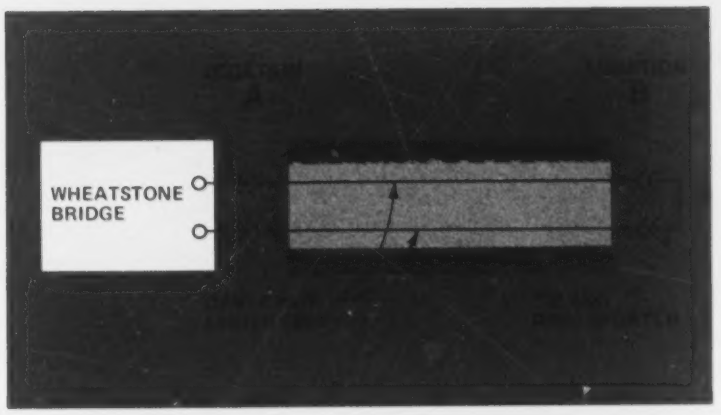
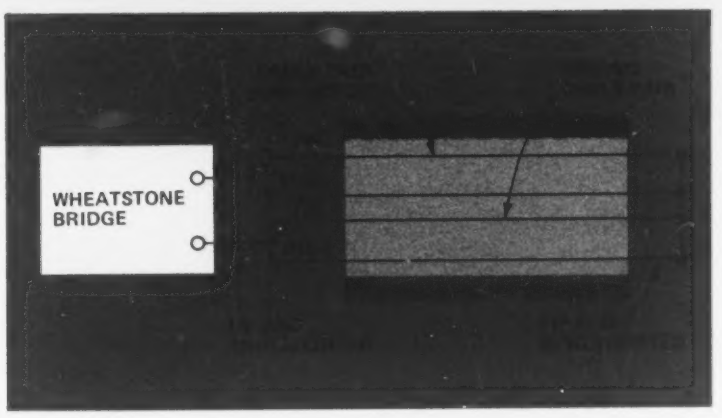


Figure 11B. Conductor resistance balance measurements.



To measure the conductor resistance balance, the Wheatstone bridge should be connected as shown in Figure 11B, using a second pair in the same cable as a third conductor. Individual measurement of the tip and ring conductors of the pair under test is necessary and is performed as shown by the arrow connections. First the tip then the ring of the pair under test is measured using the second cable pair as a return path.

Example:

For 6.2 kft of 22 gauge cable,

Loop resistance

= 6.2 kft x 32.28 ohms/kft
= 200.14 ohms

Average tip or ring resistance

$$= \frac{200.14}{2} = 100.07 \text{ ohms}$$

Average tip or ring resistance plus third-conductor resistance (1/4 of loop resistance)

= 100.07 ohms + 50.03 ohms
= 150.10 ohms

0.5% Tolerance in ohms

= 150.10 ohms x .005
= .75 ohms

Therefore, total resistance of tip or ring plus the resistance of the second cable pair should be between 149.35 ohms (150.10 - .75) and 150.85 ohms (150.10 + .75).

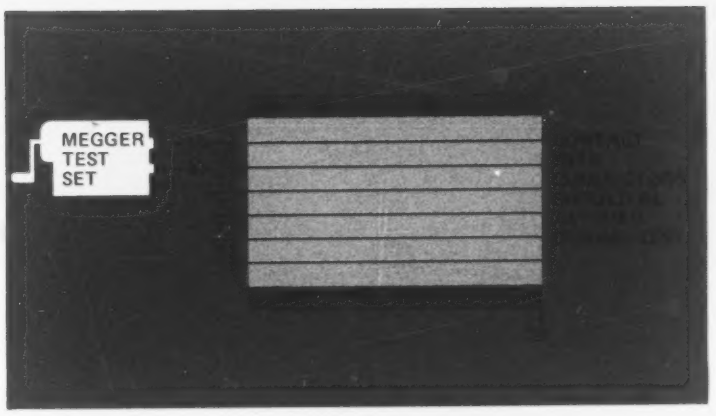


Figure 12A. Megger test on one cable pair.

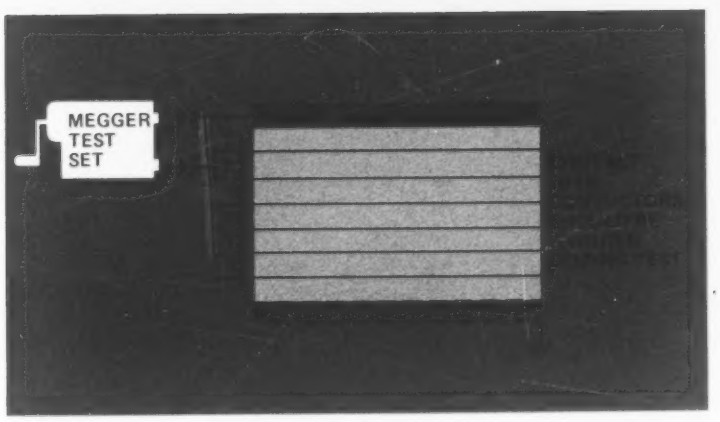


Figure 12B. Megger test of cable pair to ground.

Insulation Resistance Measurement

A megger test set is used to measure the insulation resistance between each conductor and ground and between each conductor of the pair. The distant end of the pair should be open and ungrounded for this test.

The operator should exercise extreme caution in avoiding contact with any of the terminals or wires during this test since the circuit is at a potential of several hundred volts above ground.

Once the megger is put into operation the resistance is then indicated on the megger test set meter. This resistance reading is then divided by the length in miles of the cable under test. The insulation resistance should be the same between the two conductors of a pair (Figure 12A) and between the pair to ground (Figure 12B). Paper insulated cable should indicate a minimum insulation resistance of 500 megohms per mile. Polyethylene insulated cable should indicate a minimum insulation resistance of 1000 megohms per mile.

Frequency Response

For PCM use, the cable pair frequency response must be checked to at least 1 MHz. Although the maximum energy of the PCM band occurs around 772 kHz, a considerable portion of energy exists up to 1 MHz. The frequencies above 1 MHz decrease in importance, so that measurements above this limit are not necessary.

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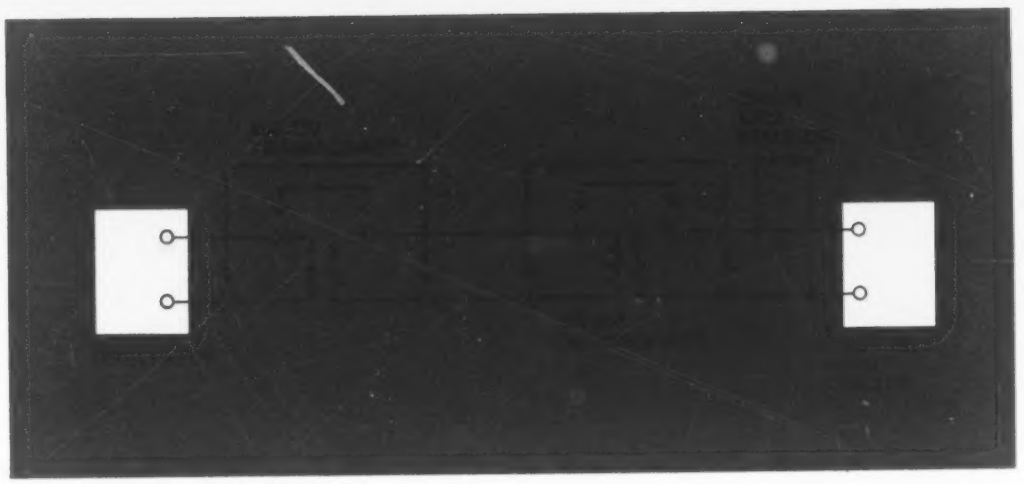

Figure 13A. Equipment arrangement for calibration.

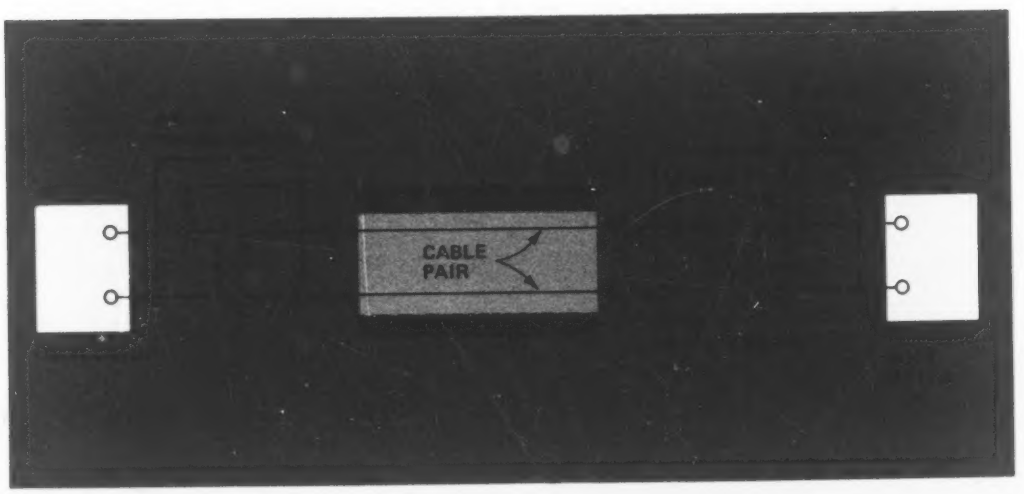

Figure 13B. Equipment arrangement for cable frequency-attenuation test.

Likewise, the frequencies below about 400 kHz decrease in importance for transmission of PCM circuits, so they can therefore be neglected during measurements.

To verify the frequency response and insertion loss of the test transformers, test equipment should be connected as shown in Figure 13A. The test transformers are necessary if the output impedance of the oscillator and/or the input impedance of the voltmeter is 600 ohms. At the frequencies of interest, the cable impedance is approximately 130 ohms. The oscillator frequency should be set to 1 MHz and the meter tuned to this frequency. The oscillator output level should be adjusted to indicate 0 dBm on the meter.

Tuning the oscillator between 400 kHz and 1 MHz, and tracking the frequency with the voltmeter tuner, any variation about the 0 dBm level, at

every 50-kHz interval should be noted and recorded.

At the end of the test the oscillator output power must still be 0 dBm on the meter. The oscillator output level during the frequency run on the cable must not be changed.

To check cable attenuation the test equipment should be connected as shown in Figure 13B. The oscillator should be tuned from 400 kHz to 1 MHz, and the received level reading should be recorded at every 50 kHz interval. In addition, the received level at 772 kHz should be recorded. This frequency is used in transmission calculations for the PCM carrier, and can be used to verify the cable attenuation figures used for calculation.

The amount of progressive attenuation of the cable should be plotted at the end of the test and any abrupt change in received level should be noted since this would indicate a change in the transmission characteristics of the cable. Paper-insulated cable will usually exhibit a somewhat higher attenuation than PIC, perhaps 0.5 to 1.0 dB greater per thousand feet at 772 kHz.

Economic Benefits

Returning to the original question – what is at fault on a system with new equipment and older cable, when only part of the total number of channels function properly? With pulse reflection, resistance, and frequency response tests complete, and with any unserviceable pairs removed, this question may now be answered.

Once equipment checkout is complete and verification of adequate crosstalk coupling loss in the system is made, the communications equipment user may then reap the economic benefits of using previously installed cable for his new equipment.